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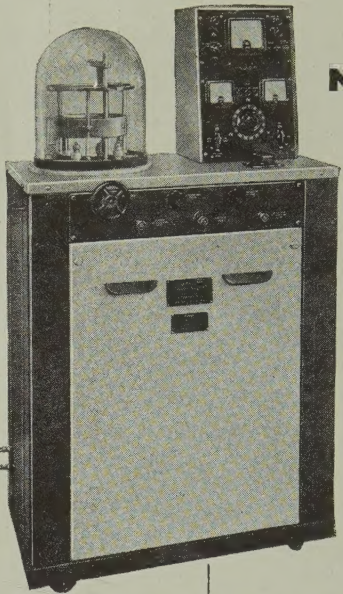

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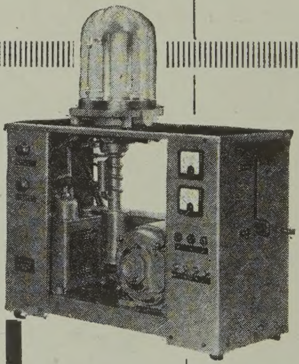

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AGENTS THROUGHOUT THE WORLD

SPECIAL ARTICLE

Post-war developments in geophysical instrumentation for oil prospecting

By D. T. Germain-Jones, Ph.D., F.Inst.P., British Petroleum Co. Ltd., London

Noteworthy advances have been made in geophysical apparatus for oil prospecting purposes over the past twelve years. Highly sensitive apparatus for accurate registration in an aeroplane of anomalies in the earth's magnetic field is being employed with considerable success. Gravimeters weighing only 5 lb and measuring changes in the earth's gravitational field with an accuracy of the order of 1×10^{-8} g are in widespread use. Highly portable low frequency seismic apparatus will register with ease refracted waves up to distances of twenty miles, and seismic reflexion equipment of complex design, but rugged and portable, will record reflexions of various frequencies from depths of many thousands of feet. Routine seismic surveys are conducted from ships over water-covered areas, and for accurate location purposes on surveys over prospects under the sea it is customary to employ radio surveying aids. The recent introduction of magnetic recording for seismic surveys offers wide scope for improvements in the seismic technique; and new methods of displaying the recorded information are likely to help greatly the process of interpretation. Remarkable ingenuity has been shown in the development of radioactive and other forms of well-logging devices.

October 1955 the retiring President of the Society of loration Geophysicists(1) described developments in physical prospecting over the past twenty-five years, as ows:

. . . We have progressed from crude instruments to ectronic marvels. The only comparable developments applied science which have paralleled geophysics have een radio, television, nuclear energy and air-conditioning. ll were conceived in the past fifty years, all were developed the past twenty-five years. Yet geophysics at the present me can claim more value of product and more service to ankind."

o many physicists outside the oil industry this may e as a surprise, because so little is known of the work he comparatively few physicists whose job it is, with their ogical colleagues, to find oil. It has not been an easy in the past to find the necessary reserves; and the task he future, with the majority of "easy" targets already ted and geological surface evidence becoming scarcer or e complex over the possible targets which remain, will ome yet more difficult and more dependent on the abilities he geophysicist.

here has been little change since the war in the basic niques employed by the oil geophysicist, though there e been spectacular developments in instrumentation nded primarily to improve the resolving power of the hods and to speed up exploration as a whole. Current arch gives grounds for hoping that, in the future, the physicist may receive further help from geochemical, o-wave and radioactive techniques which may detect ctly the presence of deeply buried oil-bearing beds which present can be proved only by the drill after the geosicist has furnished a map indicating appropriate structural ditions. A full description of instrumental developments r the past decade would take up much space, but a brief ew under appropriate headings will be attempted.

MAGNETIC METHOD

rior to about 1946, all measurements of the earth's gnetic field for purposes of geophysical exploration were undertaken with a suitably designed magnetometer set up on a tripod. This instrument was naturally affected by the presence of local magnetized bodies, and the rate at which observations could be made over an area depended greatly on the topographical conditions. Since the end of the war, however, vast areas of the world have been explored magnetically by an airborne instrument whose development by the Gulf Research and Development Co. Ltd.(2) was sufficiently far advanced early in the war for it to be applied with some success in the search for enemy submarines. The airborne magnetometer has revolutionized magnetic prospecting, and finds its greatest application in oil exploration in furnishing data in a rapid manner from which an appraisal can be made of the total thickness, and the variations in that thickness, of the sedimentary rocks in the area under consideration. Such information is an important prelude to oil exploration in areas of the world where little or nothing is known of the depth of the igneous basement. Along any given flight line, the position of which is fixed either by air photographs linked to a ground triangulation or by the employment of radio-survey techniques, continuous recordings can be made of the variation of the total intensity of the earth's magnetic field to an accuracy of 1 or 2 γ ($1\ \gamma = 10^{-5}$ gauss). From the shape and amplitude of the magnetic variations on the profile, or of the anomalies contoured over a network of flight lines, the approximate depths of the basement at various points can be estimated.

The airborne instrument (Fig. 1) is a flux-gate (or saturation) magnetometer of very high sensitivity. The flux-gate element consists of two thin strips of high permeability alloy each wound with identical exciting windings. The windings are connected in series but in a manner which produces magnetization in opposite directions in the two strips when a common current is passed. Around the system is wound a secondary winding as indicated in Fig. 2. When in use, an automatic mechanism keeps the axis of the element alined with the direction of the earth's magnetic field.

The cores are excited by alternating current with a frequency of the order of 1000 c/s and of magnitude more than sufficient cyclically to drive the cores beyond their saturation point. The back e.m.f. caused by the induction field of each core distorts the waveform of the voltage across its primary coil, and the entry into the saturation region of the hysteresis curve of the core material, twice in every cycle of the exciting current, gives rise to sharp discontinuities on the waveform. In the presence of an ambient magnetic field, the saturation point is reached earlier in the cycle if the field is aiding the magnetization resulting from the exciting current, and later if the field is in opposition. Thus a slight phase change in the occurrence of the discontinuities over the cycle results from the introduction of a relatively low intensity magnetic field such as that of the earth. The resultant voltages across the primary coils on the two legs of the element are demonstrated in Fig. 2. With the exception of the very slight phase difference of the discontinuities, the waveforms are similar but in opposition. Thus practically no current is induced in the secondary winding except where the momentary unbalance due to phase shift of the discontinuities gives rise to a sharp voltage "pip," the amplified form of which is shown in Fig. 2. It can be shown that the peak value of the " is proportional to the intensity of the ambient magı field. In the Gulf airborne instrument (Fig. 3) the ou pulses are fed through a step-up transformer to a dete which yields a d.c. voltage proportional to the pulse he and this is registered by a Leeds–Northrup recorder w has a full-scale sensitivity of about 8 mV. This record of the self-balancing potentiometer type, capable of resto balance over the full 10 in. scale of the recording pape one second.

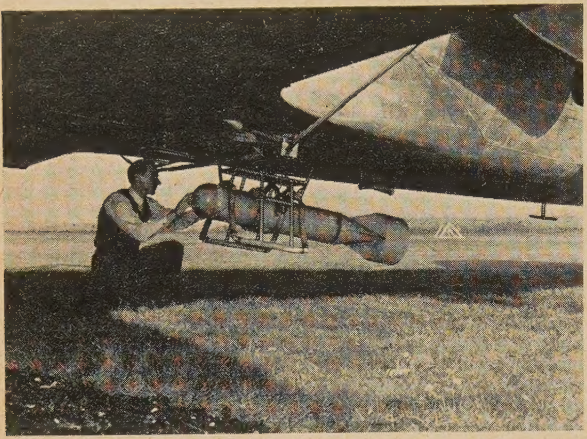

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Fig. 1. Airborne magnetic detector fitted in cradle prior to release for towing

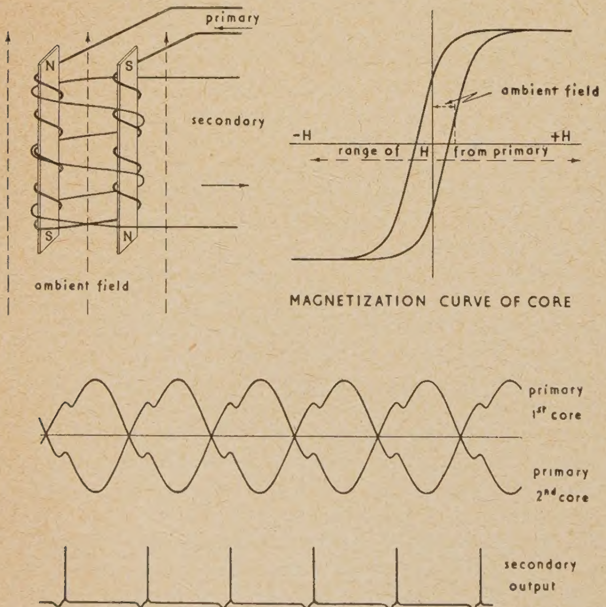

Fig. 2. Principle of airborne magnetometer

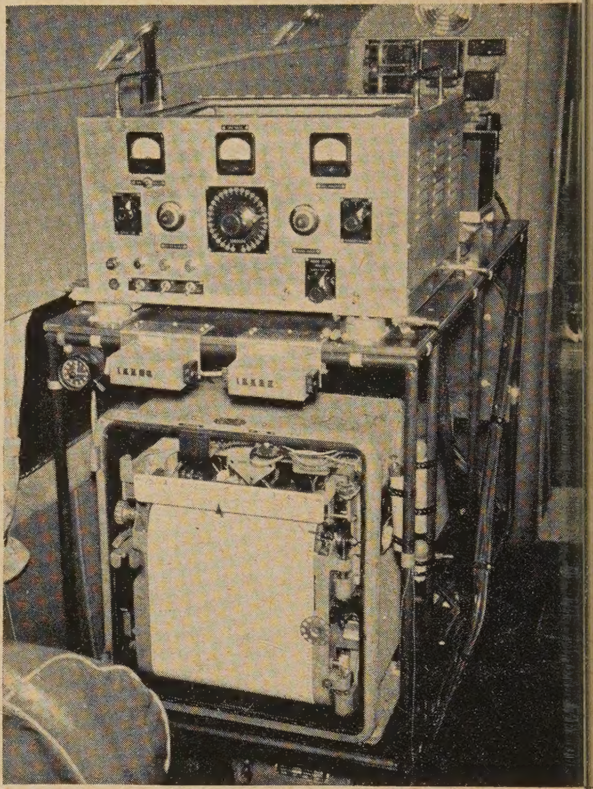

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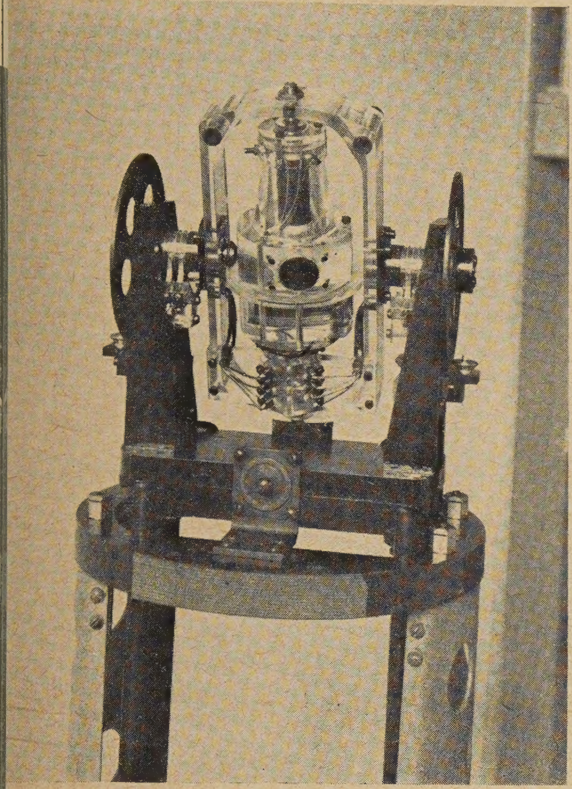
Fig. 3. Recording apparatus in aeroplane, showin Leeds–Northrup recorder

Automatic alinement of the detecting element in the ear magnetic field is maintained by means of two more flux- elements, mounted at right angles to each other and to main element on a gimbal system (Fig. 4). The volt outputs of the secondary coils of the positioning flux-g are fed to servo-motors which respond to signals from eit coil by rotating that coil into null position. When positioning coils are in the null position, the detecting elem is oriented in the direction of the field.

Recent interesting applications of the instrumenta developed for airborne magnetic surveying are for obse tions at sea, the recording element being towed behin ship, and on land where the container housing the recor element is mounted at the end of an arm about twenty long which projects from the rear of the vehicle. The instrument has been designed primarily for mining purpo

During the past three or four years parallel investigati in the U.S.A.$^{(3)}$ and in this country$^{(4)}$ have demonstrated possibility of producing a simple and accurate "nuc magnetometer" for prospecting purposes based on rmination of the frequency of free precession around the n's field of the protons in a sample of water. A bottle vater is magnetized in a direction perpendicular to the n's field by passing a current through a coil wound around bottle. When the current is switched off abruptly the netic moment vector precesses around the earth's field ction and induces a small alternating voltage in the coil.



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ig. 4. Principal component of magnetic detector head. The three fluxgates arranged in a gimbal system

measuring the frequency of this voltage (about 2000 c/s England) the field strength can be determined with an uracy of the order of ±0·5 γ. Instruments of this type e already been employed with success in airborne surveys iron ore, and in magnetic observations at sea with the ector towed behind the ship.

GRAVITY METHOD

y 1939 gravimeters were in use which had the sensitivity ssary for the practical requirements of prospecting, they could detect changes of less than one part in ten ion of the earth's gravitational field. Apart from the culties of producing a basic system which would give the red sensitivity, there was also the great problem of inating the effects of temperature changes. This was come by utilizing materials with low temperature ficients of expansion, the incorporation of temperature pensating devices, and the maintenance of uniform perature by thermostatically controlled electrical heating. the end of the war the weight of the average instrument its heating batteries was approximately 50 lb.

In 1948 two new remarkable gravimeters appeared in the U.S.A., the Atlas and Worden instruments. Temperature effects in these are practically eliminated by a very efficient temperature compensating device, the employment of a quartz element working in an evacuated chamber and the use of a vacuum flask as the instrument case. The Worden instrument weighs about 5 lb and does not require any heating batteries. Needless to say, it has found wide application, especially in areas where accessibility is a problem; and it has been of considerable value as a geodetic instrument for linking by air the widespread pendulum stations and for widening the net of gravity bases throughout the world. Readings at a station, to 0·01 mgal (i.e. 1×10^{-8} g) take only a few minutes, and the number of stations which can be observed in a day is limited almost entirely by the time of transportation between stations and by the occasional visits to "base," or to previously observed stations, in order to keep track of the drift which still exists despite all the measures taken to counteract it. It is quite normal to make observations at twenty-five new stations, each one kilometre apart, in one day.

The principle of the Worden meter is illustrated in Fig. 5, all the essential elements being of quartz and weighing, altogether, about 5 mg. Fig. 6 shows the complete instrument. The system is held in unstable equilibrium about the axis *AA*, the moment of the gravitational pull on the weight being opposed by that of the pre-tension spring. An increase in gravity causing a slight counter-clockwise rotation of the moving system will produce a decrease in the angle between the spring and the inclined arm attached to its base, and the opposing moment of the spring will therefore be lessened. By introducing this element of instability the system can be made extremely sensitive. The movement of the pointer is observed through a microscope, and gravity changes are measured by returning the pointer to the null position by rotating a finely graduated dial which reacts on the system *via* an adjustment spring. Actually, two adjustment springs are provided, one stronger than the other and each with its own dial. One is for use over wide ranges of gravity, and the other when small-range, detailed observations are required. The whole system is enclosed within an evacuated chamber which, in turn, is placed in a vacuum flask.

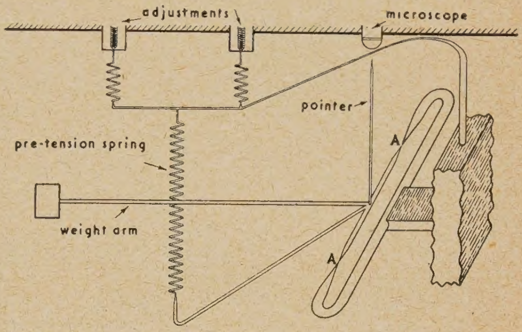

Fig. 5. Principle of Worden gravimeter

For exploration over water-covered areas the normal land meter has been employed on a platform fixed to the top of a large tripod with its legs resting on the rock bottom, and also in specially constructed diving bells. These diving bells, housing the meter and its operator, have been employed fairly extensively in waters as deep as 130 feet. Just before the war the Gulf Research and Development Co. Ltd.(5)

perfected an underwater meter which could be lowered to the bottom and operated completely by remote control from the ship. Since the war other underwater instruments have been introduced and find increasing application as the search for oil is extended to prospects beneath the sea.

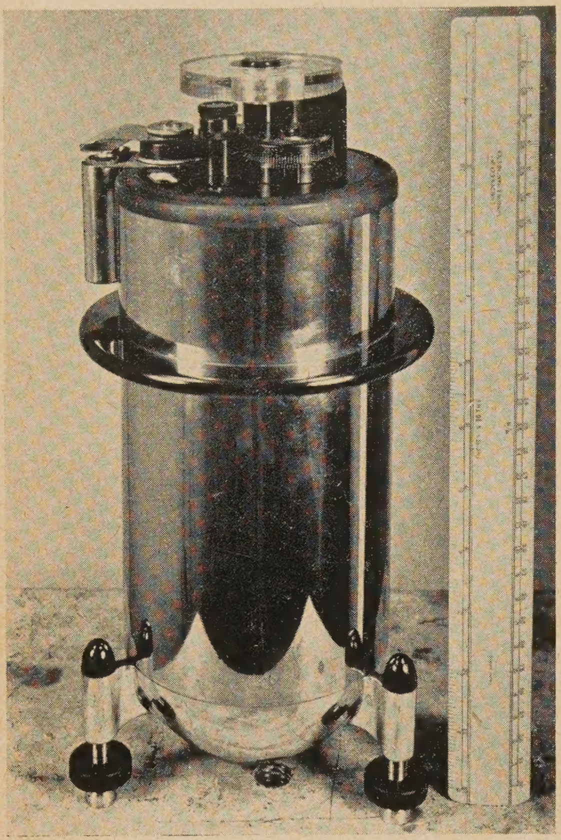

Fig. 6. Worden gravimeter

It has been realized for some years that a gravimeter which could be designed to work in a borehole down to depths of hundreds, preferably thousands, of feet would be of value in a number of ways, particularly for the determination of rock densities *in situ*. There are great difficulties—limitations of space, unavoidable rough treatment, the temperature gradients in the borehole—and, although much work on the project has been undertaken, it has not yet led to the production of a suitable instrument. R. L. G. Gilbert(6) of Cambridge succeeded in making the first rough measurements of gravity changes in a borehole with a prototype instrument in 1952, but the conversion of the prototype to a practical piece of equipment has still not been accomplished.

SEISMIC METHOD—REFRACTION

When the seismic reflexion technique became fully established, some years before the war, it was taken up in a big way, and only a small number of operators continued to employ refraction techniques for oil exploration. Among the latter was the British Petroleum Co. Ltd.,(7) which has proved beyond doubt that, for large structures of the type existing in the rugged foothill belt of S.W. Persia, the refraction method is superior to the reflexion technique. This is still true today, not only in Persia but also in certain other parts of the world. During the past three years real value of refraction has become more widely apprecia and, for the first time, it has become possible to purch complete modern low-frequency refraction equipment suita for long-range observations.

At long ranges, i.e. ten to twenty miles, it is usually ad able to employ apparatus which has a good response frequencies as low as 2 c/s. Before the war this entailed use of large, heavy components in the amplifiers, particula the transformers and chokes, and the geophones themsel weighed as much as 75 lb. Wartime developments in electronic field, especially in miniaturization and tropicali tion of components, changed the picture considerably, a low-frequency refraction apparatus today is highly portab rugged and reliable in all climatic conditions. Mod geophones (Fig. 7) weigh less than one-quarter of th pre-war counterparts, and a modern twelve-channel amplifi unit weighs only about 35 lb. A recent development is refraction amplifier employing transistors throughout, and unit incorporating twelve channels weighs only 18 lb. Th amplifier response of a typical low-frequency refractio amplifier is shown in Fig. 8, the choice of filter setting o any given survey depending largely on the background nois which it is desired to minimize. The response of a typica refraction geophone is also shown.

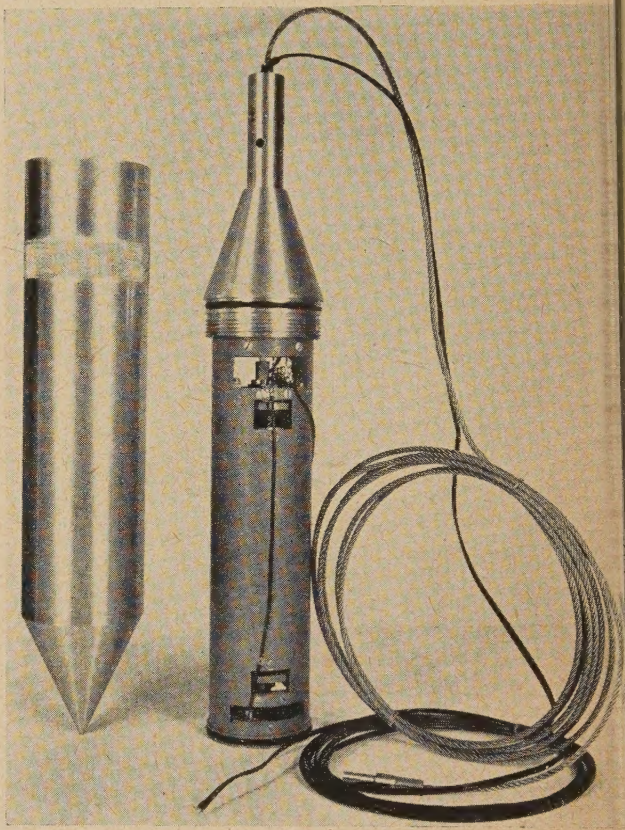

Fig. 7. The BP refraction swamp geophone. Length 21 in.; diameter $3\frac{1}{4}$ in.; weight 14 lb; natural frequency 3 c/s

It is of interest to note that in difficult swamp and jungl country as exists in Papua the introduction of small heli copters for transportation of field personnel, their equipmen ıd explosives, has greatly increased the output and efficiency f work.

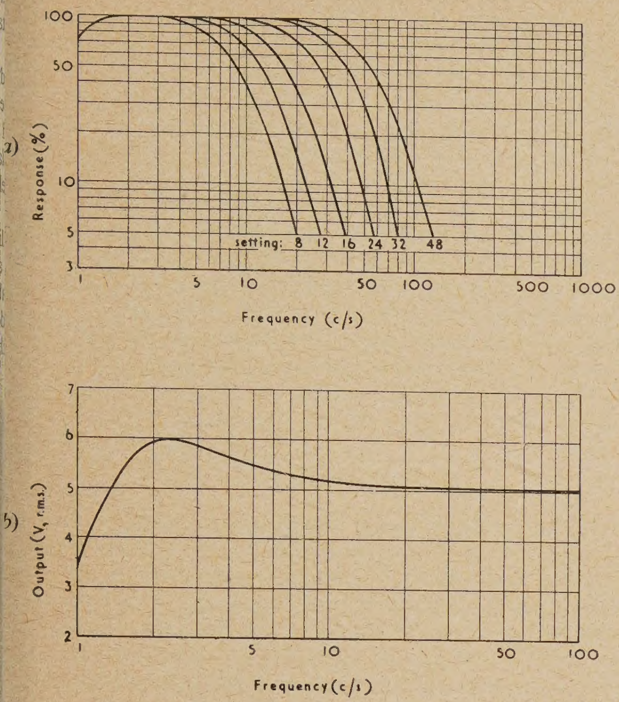

Fig. 8. Characteristic curves of refraction amplifier and refraction geophone

(*a*) Amplifier response at various filter settings; (*b*) S-36 seismometer response at a constant velocity drive of 1 in./s.

SEISMIC METHOD—REFLEXION TECHNIQUE

It is in the field of seismic reflexion techniques where erhaps the greatest advances in instrumentation have been ıade. "Conventional" apparatus is still largely employed, ut its flexibility to cope with a wide range of field problems as been increased enormously. Modern reflexion geophones eighing less than 1 lb make it possible easily to employ a attern of multiple geophones per trace, connected in series r in a series—parallel arrangement, which will effect an nprovement in signal-to-noise ratio by a partial cancellation f horizontally directed ground noise and summation of the ertically directed reflected signals. For this purpose as many s thirty-six geophones have been employed on each trace of twenty-four trace outfit, making 864 geophones in all. Connexions to the amplifiers from all the detector stations re made through a single plastic-covered, flexible multicore able with a diameter of about 0·3 in. Fig. 9 shows modern eflexion equipment mounted in a truck.

The circuitry of modern reflexion amplifiers is exceedingly omplex. A standard system today, designed to deal with eismic frequencies of, say, 15–120 c/s, may incorporate the ollowing features.

(*a*) An amplifier with a gain of 120 dB which can handle ıputs from 1 μV up to 100 mV over a frequency range of 0 to 200 c/s with less than 1% distortion.

(*b*) Automatic volume control with adjustable speeds of esponse which maintains the output constant to within 6dB or the $10^5 : 1$ range of inputs mentioned above. Provision or various combinations of "attack" and "release" times.

(*c*) LC band-pass filtering, two sections of filtering being used for low-frequency rejection and perhaps two for high-frequency rejection. Up to six cut-off switch positions may be provided on the high-frequency side over a range of 40 to 120 c/s, and perhaps ten on the low-frequency side, from "out" to about 65 c/s. Hundreds of filter combinations are therefore possible. Filters with cut-off slopes as great as 80 dB/octave are sometimes provided.

(*d*) Provision for recording either "straight" or "mixed" records by selector switches. Some equipments provide dual outputs for simultaneous recording of both types on paper 10 or 12 in. wide which will accommodate fifty or sixty traces.

(*e*) The employment of "trip" circuitry to maintain pre-suppression until, and to introduce pre-set filtering when, the first direct onsets of seismic energy have been recorded. This is important for subsequent computations on the seismogram, as clear-cut undistorted "first arrivals" are valuable for correction purposes.

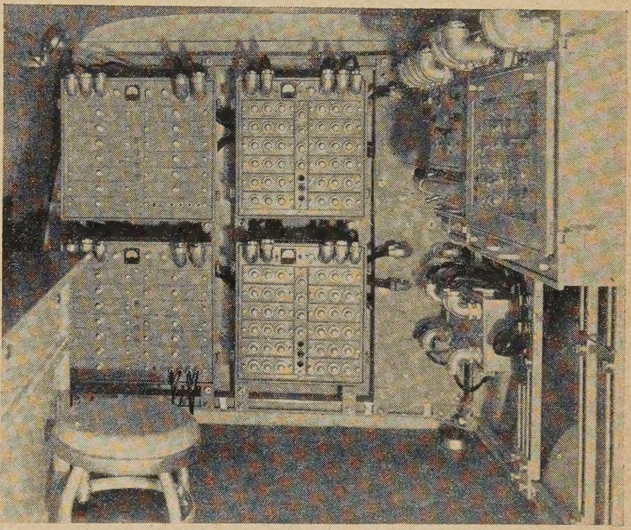

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Fig. 9. Reflexion equipment mounted in truck

The organizations employing reflexion equipment have their individual ideas on the various features required to be incorporated in a recording system. One large oil company, for example, uses a filter whose pass-band varies continuously down the seismogram to compensate for the change in the frequency spectrum of the reflected energy with depth. Amplifiers are being produced with a linear variation of phase shift with frequency over the operating range so that each frequency component in the signal suffers the same time shift in the amplifier. Printed circuits in the amplifiers are also being adopted.

Considerable improvements have been made in the design of recording cameras. A modern recording unit incorporating fifty moving-coil type galvanometers, capable of timing seismic events to 0·001 s on photographic paper 10 in. wide, weighs little more than 40 lb and measures about 18 × 12 × 10 in. Practically all cameras employ a timing device, the basis of which is an electrically maintained tuning fork; but during the past year a new type has become available which employs a crystal oscillator (Fig. 10). It has a number of possible advantages over the conventional type, one of which is that in use with magnetic recording systems (to which reference will be made later) the timing lines on the record can be synchronized to a timing signal from the magnetic tape on play-back.

Research into the possible employment of higher seismic frequencies in order to improve the resolution of the underground structural picture and to facilitate mapping of shallow structure has led to the production of so-called "high resolution" apparatus intended to record reflexions within the band of approximately 100 to 300 c/s. Surveys already undertaken with this equipment have shown that reflexions with these higher frequencies can be recorded from depths of at least 5000 ft in some areas, and they have demonstrated also that satisfactory reflexions can sometimes be recorded from horizons which cannot be picked up at all by the conventional equipment. The tendency at the present time is to produce complete wide range equipments which will cover all possible requirements, i.e. low-frequency refraction (2–30 c/s), conventional reflexion (15–100 c/s) and "high resolution" (100–300 c/s).

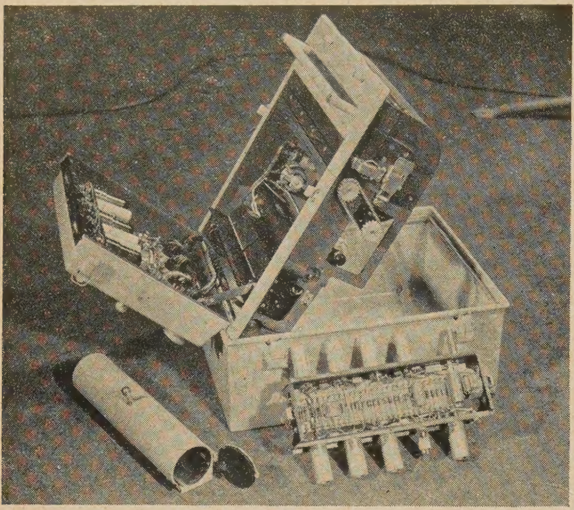

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Fig. 10. Modern recording camera with crystal-controlled timing

The use of high explosive to initiate the seismic disturbance is still widespread, but a new technique employing a "thumper" is having some success. The signal is provided by a three-ton weight dropped ten feet on to the ground from a mobile crane. The seismic energy so produced is small, and this difficulty is overcome by recording the signals on magnetic tape from a series of "thumps" and compositing the separate records to produce a final seismogram which has adequate signal-to-noise ratio. It is reported that this technique has been successfully applied at sea, the weight being dropped on the surface of the water.

MARINE SEISMIC PROSPECTING

Important developments have taken place since the war in instrumentation for marine seismic prospecting. For some years it was the custom to set the detectors, which were basically land-type geophones mounted on gimbals to ensure proper levelling, on the ocean bottom, either by lowering from boats or by dragging the entire assemblage of geophones a connecting multicore cable from one position to the ne Today, however, the whole operation is a continuously movi one, the detectors being pulled through the water at consta speed on a "streamer" at a depth which is kept approximate constant, and the explosive charges are detonated at t appropriate position relative to the "streamer" at tim determined by the speed of the boat so that the require coverage of the deep reflecting horizons is obtained. Piez electric or magnetostrictive type transducers are bei employed for marine work which can be housed as integr parts of the cable itself, thus forming a single, complet streamlined unit which is towed by the ship. Such work very fast compared with land operations, and 500 miles traverse per month, involving perhaps 3000 "shots," can observed fairly easily. Work in the open sea usually requir the use of modern radio surveying aids such as the Decc Shoran or Loran techniques.

MAGNETIC RECORDING

The introduction during the past two years of magnet recording for seismic prospecting, particularly for reflexi purposes, promises to revolutionize seismic techniques. T fundamental advantage which magnetic recording has to off is that a recording can be made at each detector station the whole of the seismic energy within a wide band of fr quencies, wide enough to include all those frequencies wh might prove of practical value. Such a record can then played back any number of times, with different filter settin in the play-back amplifier, to determine the optimum filte setting for the resolution of reflexions. One obvious appl cation of such equipment is as an experimental unit f determining in a new area the best working characteristics f conventional equipment which is to undertake the actu survey of the area, thus saving a great deal of expensi experimentation by the conventional party before it ca commence its effective work. In addition, however, it ha other advantages. They are:

(*a*) records from a number of shots can be added (com posited) to improve signal-to-noise ratio. This applicatio has already been mentioned in connexion with the "thumper"

(*b*) the records can be corrected for elevation and weather ing differences, and for "move-out" by adjustment of th play-back heads on each channel.

The ability to produce records with the major correction already applied offers considerable scope for "pictorial" representation of the survey results in a form which, i addition to being of immense value to the geophysical inter preter, can be appreciated much better by his geologica colleague. The final records can be produced on a reduce scale either as conventional seismograms, or as variabl density or variable area recordings; and when laid, in order side by side and re-photographed, a complete seismic sectio along a given traverse, showing *all* the useful seismic information, can be obtained.

Three methods of modulation are employed in magneti recordings at the present time. They are:

(*a*) direct modulation, in which the intensity of magnetization of the magnetic material is proportional to the signa amplitude, a high frequency bias field being used to remov the effect of magnetic hysteresis;

(*b*) frequency modulation, in which a saturating carrie frequency of unmodulated value around 3 kc/s is applied t the tape. During a recording the frequency of this carrie viates from its unmodulated value by an amount proortional to the instantaneous value of the signal being corded;

(*c*) pulse width modulation, in which saturating pulses are plied to the magnetic tape at a rate of 800 or 1600 per cond, the width of the pulse being proportional to the stantaneous value of the signal.

The recordings themselves are made either on long tape d from a magazine, on tape wrapped round a drum or on disk.

There are thus a number of different types of magnetic cording equipment available today, and their advantages nd disadvantages are still being considered by many ganizations engaged in geophysical prospecting before ming to a decision on which type is likely to have the eatest useful application. The confusion results mainly om the extremely rapid development of this new form of cording, but when the position becomes clearer there can little doubt that there will be a very considerable investment magnetic recording equipment.

OTHER MODES OF RECORDING

Because of the time involved in computations on conentional seismograms, and the difficulty in identifying all ossible reflected events, it is customary to concentrate tention on only a few salient events and to "carry" them ong the traverses which are observed. As intimated earlier, tempts are now being made to convert recordings more rectly into geologically significant cross-sections; and to xpedite the process with conventional seismograms, semiutomatic machines are being developed which can suitably onvert the form of the seismograms and facilitate the introuction of various corrections. One such machine is the eynolds plotter.(8)

The time corrections which have to be applied to a seismoram are not the same for all traces and, since in a convenonal seismogram there is usually considerable overlapping f the traces, it is evident that there is a need for "channelizg" the individual traces so that independent treatment can e applied to each before a satisfactory cross-section can be uilt up. There are various modes of recording which will cilitate this "channelizing" process, one or two of which or example, the variable density type) are peculiarly suited r pleasing pictorial representation of a seismic cross-section. our of these forms of recording are illustrated in Fig. 11. is probable that one of these recording techniques, used in onjunction with magnetic recording apparatus, will evenally furnish the most flexible and most efficient means of tilizing the information which the seismic method can offer.

WELL-LOGGING DEVICES

A description of instrumental developments in the field of ell logging would require another article. It may help to ive some idea of the degree of these developments to mention hat for radioactive logging purposes a particle accelerator(9) r the production of an intense beam of neutrons has been eveloped which is small enough to be lowered into a boreole. This miniature version of a Van de Graaff particle

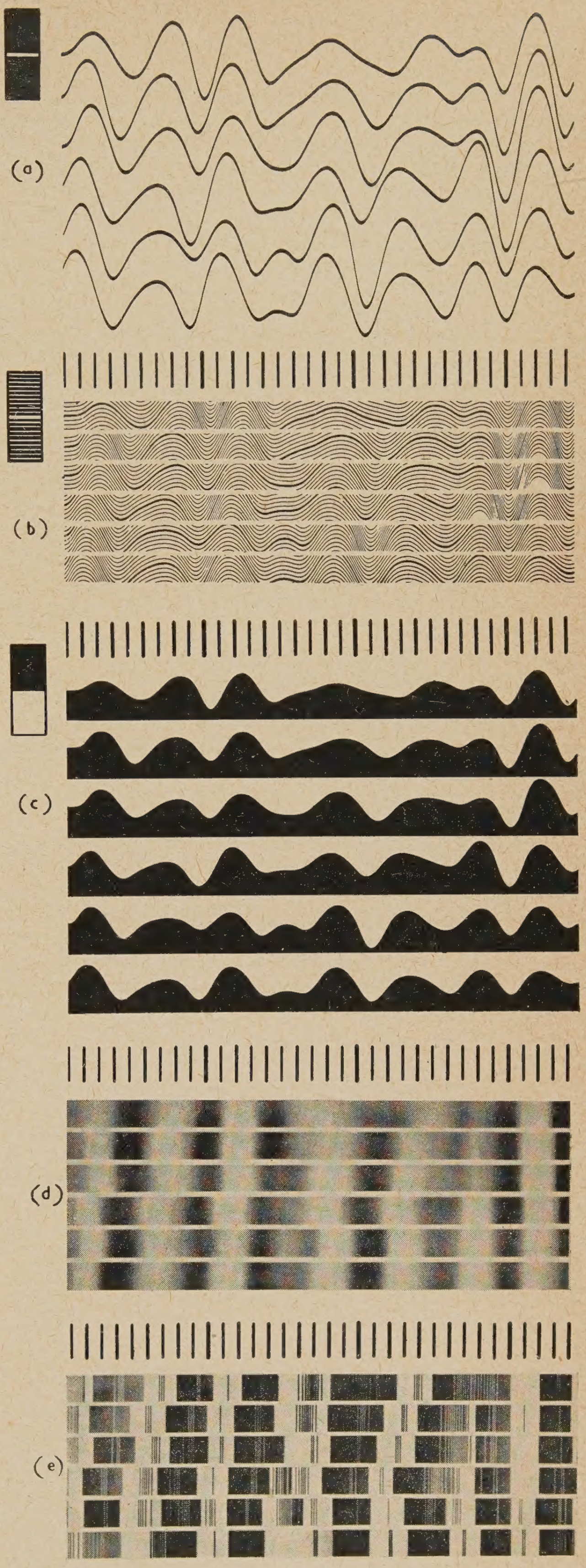

Fig. 11. Modes of seismic recording

(*a*) Conventional single spot; (*b*) multiple spot clipped; (*c*) variable area; (*d*) variable density; (*e*) coded density.

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accelerator is 3 in. in diameter and 47 in. in length, and generates potentials up to 200 000 V. It will be used mainly for the determination of rock porosities, for which purpose it is customary at the present time to use instruments with plutonium–beryllium or radium–beryllium sources of neutrons.

One important logging device which is proving most valuable to the geophysicist is the continuous velocity logger, three or four types of which are at present in use. For over twenty years it has been customary to make determinations of the average velocity through the rocks down to various depths in the sedimentary succession, and of the velocities over predetermined intervals, by recording the travel times of a seismic disturbance from the surface of the ground to a detector suspended in a borehole on the end of a cable. Equipment became available about three years ago which enabled a continuous velocity log of the borehole to be obtained with very much finer resolution of the velocities pertaining to the individual rock members of the succession.

The instrument developed by the Magnolia Petroleum Co.(10) is composed of an acoustic pulse generator separated from a receiver by an acoustic insulator five feet long. High intensity ultrasonic pulses are transmitted twenty to thirty times per second to the formation surrounding the borehole, and means are provided automatically to select and to record the travel time of the onset of the seismic disturbance arriving at the receiving transducer. Power supply to the instrument, and the return of the output signal to the recording equipment at surface, is effected by means of a multicore cable on which the instrument itself is suspended. The instrument traverses the borehole at a speed of 100 to 150 feet per minute, and a continuous log of the velocities throughout the borehole is produced as a pen recording on paper or film 12 in. wide running at a speed of about 18 in. per 1000 feet of travel of the logging instrument.

Apart from its application as an instrument for furnishing velocity information for use in the interpretation of seismic surveys, it affords also the means of securing detailed velocity information which should help in our understanding of the mechanism of reflexion and refraction within the rock system of the earth. Experience has shown, too, that the continuous velocity logger can be most useful for geological correlation purposes between boreholes over wide areas.

Earlier in this article it was mentioned that a borehole gravimeter which would enable rock densities at depth to be determined would be a valuable instrument. Research investigations in the field of radioactive well logging(11) have now resulted in the development of a logging device which will measure rock densities based on the principle that the degree of scatter of γ-radiation from a strong source of fairly hard γ-rays in the borehole is a function of the density of the rock surrounding the hole. An instrument of this type(12) is now being employed in many areas to secure density data as an aid to the better interpretation of gravity surveys.

ACKNOWLEDGEMENTS

In this article it has been possible only to cover briefly t developments which have taken place in geophysical insti mentation since the war. Its preparation has been facilitat by information supplied by a number of manufacturers geophysical equipment and by firms who undertake ge physical investigations under contract. The writer is pa ticularly indebted to the following:

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Contrast arising from elastic and inelastic scattering in the electron microscope

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The contrast due to elastic and inelastic scattering of electrons in the electron microscope is calculated on a wave-optical basis. Various approximations are made, especially in the case of inelastic scattering where additional scattering data is required for a rigorous analysis. It is shown that the major contribution to contrast arises from the gap left in the illuminating wavefront by the inelastically scattered electrons. The next most important effect is by phase contrast with elastic scattering. In-phase or amplitude contrast is very small, and the inelastically scattered electrons have little effect except for extended objects.

fter many years of discussion, there now appears to be eneral agreement on the limiting resolving power of the ectron microscope as set by diffraction and spherical erration.(1) For conventional types of objective lens of ptimum design and aperture, a point radiating object or its ore realistic practical equivalent could be imaged as a iffraction disk of radius as small as 2 Å. With so high a esolving power, the problems of contrast become of paraount importance. Indeed, contrast and resolving power ecome so closely inter-related that consideration of one is eaningless without the other.

There has so far been no very satisfactory theory for ontrast which effectively includes the effect of coherent and coherent scattering, together with the phase effects which re of such importance in the electron microscope where the bject is largely a phase object. The most useful attempt at valuating the contrast so far has been by Boersch,(2) and laser(3) has applied optical wave theory to the imaging echanism, but no comprehensive results on the contrast ave been evaluated by them.

In the present paper, an attempt is made to present a fficiently complete theory of the contrast resulting from oherent and incoherent scattering for single atoms, and to valuate the contrast with the help of available scattering ross-section data. An attempt is made to keep the theory imple so that its relation to the physical processes is easily pparent.

In the theory, certain simplifying approximations are made. n the first instance, the contrast due to coherent and inoherent scattering is treated separately.

CONTRAST DUE TO COHERENT SCATTERING

In past theories, the contrast due to coherent or elastic cattering has been estimated by calculating the fraction of he irradiating electrons which are scattered outside the bjective aperture, or diffused outside the relevant image area y the spherical aberration when no aperture is present. The ontrast for single atoms has been calculated by integrating he intensity of the scattered wave outside the limiting angle θ_0) set by the aperture.(1,2,4,5) Thus, if $I_0 d\Omega$ is the fraction f the total intensity in a square centimetre of the illuminating eam scattered into a hollow cone of angular thickness $d\theta$ aking an angle θ with the direction of the illuminating eam, and containing a solid angle $d\Omega$, the contrast (C_a) as been given as:

$$C_a = \int_{\theta_0}^{\pi/2} 2\pi I_0 \sin\theta d\theta \Big/ \frac{\pi}{4} d^2 \qquad (1)$$

here d is the microscope resolution.

It is of interest to consider how far the much more accurate optical theory of contrast for a phase object can be applied to the electron microscope. It is reasonable to consider the atom as of circular symmetry, and also use the appropriate approximations for small angles. The atom might be considered as an object, the optical path thickness of which is some function of the radius (r) from the centre of the atom. This property can be expressed as a radial variation of phase difference (η) introduced in the plane illuminating wave, thus modifying the shape of this wave front. To evaluate the image contrast, it is necessary first to evaluate the wave amplitude distribution in the back focal plane (Fourier plane), and then in the image plane taking due note of the part of the wave absorbed by the objective aperture diaphragm.

Before the object, the wave is plane and of unit amplitude (the amplitude at each point being the square root of the electron intensity). This wave is represented by the vector distribution shown in Fig. 1(a). Immediately following the object, the amplitude distribution is unchanged, since no absorption takes place, but a phase change has taken place as represented by the vector distribution of Fig. 1(b).

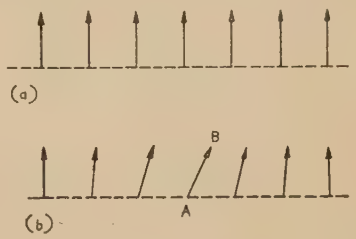

Fig. 1. Vector representation of plane (a) and perturbed (b) waves

In the Huygen–Fresnel method for calculating the wave propagation, the wave is replaced by an infinite distribution of elementary oscillators radiating spherical waves of amplitude and phase equal to the original wave amplitude. These oscillators can again be represented by the vectors of Fig. 1. A simplification results if the perturbed vectors are resolved into two parts, as shown in Fig. 2, where $\overrightarrow{AB}$ is the perturbed vector, while the components $\overrightarrow{AC}$ and $\overrightarrow{CB}$ represent a vector identical to the original unperturbed one and the difference vector respectively. Such resolution is justified in the wave theory. It is seen now that the perturbed wave is resolved into two parts, one a plane wave identical with the original, and the residual part represented by the residue vectors $\overrightarrow{BC}$ for each point in the wave. The vector $\overrightarrow{BC}$ will have an amplitude $2 \sin \eta/2$, or η if η is small, and a phase substantially in quadrature with the main wave, again if η is small. These we call the scattered wavelets, and, as a whole, they constitute the scattered wave. The propagation of the wave can now proceed in two parts. The plane background wave is not significantly affected by the aperture diaphragm, and arrives in the image plane undisturbed and still with unit amplitude. The amplitude distribution of the scattered wave in the back focal plane is obtained by integrating the effect of all the scattered wavelets at each point in that plane. According to the Huygen–Fresnel method,(6) the amplitude of the wavelets due to the elementary oscillators at a distance S is given by the original amplitude divided by $S\lambda$, when λ is the wavelength. The phase will depend upon the oscillator phase and the length of the path travelled. It can readily be shown that the path difference between the direct path from object to back focal plane and the path from an element distant r from the axis in the object plane to a point ρ from the axis in the back focal plane with a difference in radius vector direction ζ is given by: $\rho r \sin \zeta/f$ (f being the focal length of the objective lens). This leads to a phase difference $2\pi\rho r \sin \zeta/f\lambda$.

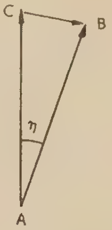

Fig. 2. Resolution of wave vector into two components

The total amplitude (ψ_ρ) at a radius ρ in the back focal plane is then

$$\psi_\rho = \int_0^\pi \int_0^\infty \frac{2\eta r}{f\lambda} \exp(i\eta) \exp\left(\frac{2\pi i \rho r}{f\lambda} \sin \zeta\right) dr\, d\zeta$$

$$= \int_0^\infty \frac{2\pi\eta r}{f\lambda} \exp(i\eta)\, J_0\left(\frac{2\pi\rho r}{f\lambda}\right) dr \qquad (2)$$

where J_0 is the zero order Bessel function.

This integral can be evaluated if η is known as a function of r. (It should be pointed out that the integral as given is only correct if η_r vanishes before r becomes very large. This results from neglect of the obliquity factor.)

The amplitude distribution in the image plane is obtained by an identical process, and is given by:

$$\psi_i = \int_0^\pi \int_0^{\rho_0} \frac{2\psi_\rho \rho}{f\lambda} \exp\left(\frac{2\pi i \rho R}{f\lambda} \sin \zeta\right) d\rho\, d\zeta$$

$$= \int_0^{\rho_0} \frac{2\pi\psi_\rho \rho}{f\lambda} J_0\left(\frac{2\pi\rho R}{f\lambda}\right) d\rho \qquad (3)$$

where R is the radius vector in the image plane. Knowing ψ_ρ from (2), the last integral can be evaluated. The limit (ρ_0) of the integral takes account of the effect of the limiting aperture. The mathematical process is the well-known Fourier transform.

In the case of electrons and atoms, available elastic scattering data give us the distribution of scatter intensity (I_θ) in angle, rather than the distribution of the effective refractive index over the atom. From this, the amplitude distributi in the Fourier plane is given directly as $I_\theta^{\frac{1}{2}}/f$. It appe unnecessary therefore to apply the first transformati equation (2). A difficulty arises, however, because the pha of the scattered wave is not known. In the optical calculati this phase angle would be taken care of by the term exp (in equation (2) (*et seq*.). This splits the integral into r and imaginary parts which correspond to the quadrature a in-phase components of the final amplitude. The pha angle is then given by the inverse tangent of the ratio these parts in the solution of equation (2). No furth change in phase angle occurs between the Fourier and ima planes since these planes are effectively cophasial, i.e. th are coincident with the wave fronts as they pass through t planes. The absence of the phase information in the scatte ing data available results only from the fact that there h previously been no need to calculate it. The information implicit in the scattering calculations, but has not bee evaluated.

If the integral of equation (2) is put equal to $I_\theta^{\frac{1}{2}}$, an integr equation is obtained with η_r as the unknown functio Solution of this equation would give the optical shape of th atom and allow a complete solution of equation (3). Apa from the difficulty of solving the equation, this seems a ve roundabout way of obtaining the missing informatio Furthermore, the fact that it is possible suggests that th phase information is implicit in the distribution of I_θ. Th will be so, provided the sign of $I_\theta^{\frac{1}{2}}$ is everywhere known, an since it has no zeros and obviously there are no disco tinuities, it clearly cannot change sign, and hence must alwa be positive. It will be shown in a later section that the pha angle can be calculated using energy considerations. It already clear, however, that, provided the amplitude of th scattered wave is small, as it is for one or only a few atom per image point, the phase angle must be near to 90°. Th phase contrast which would be obtained if the scattered wav is changed in phase by 90° by a phase plate is, therefor calculable with good accuracy since small departure of phas angle from 90° makes little difference to a cosine. This phas contrast is given by adding the scattered wave amplitude t the background to which it is now in phase, squaring to giv the intensity, and subtracting from unity. Thus:

$$C_{ph} = 1 - (\psi_i + 1)^2$$

or, since ψ_i is small

$$C_{ph} \simeq 2\psi_i$$

From equation (3)

$$C_{ph} = 2\int_0^{\rho_0} \frac{2\pi\psi_\rho \rho}{f\lambda} J_0\left(\frac{2\pi\rho R}{f\lambda}\right) d\rho \qquad (4$$

On the axis where the contrast is a maximum $R = 0$, an after putting $\rho/f = \theta$ and $\psi_\rho = I_\theta^{\frac{1}{2}}/f$, we get:

$$C_{ph} = \frac{4\pi}{\lambda}\int_0^{\theta_0} I_\theta^{\frac{1}{2}} \theta\, d\theta \qquad (4a$$

The eventual achievement of full phase contrast on a hig resolution electron microscope is in considerable doubt. I any case, some of the full effect must always be lost becaus the phase plate must be discontinued over a region in th centre to allow the background beam through. In th following section, it will be shown that a worth-while pro portion of the promised phase contrast can be achieved b slightly defocusing the image.

OUT-OF-FOCUS PHASE CONTRAST

It is well known in optics that a phase object becomes visible when the instrument is defocused. This results from the fact that the act of defocusing introduces a phase difference between the peripheral part of the scattered wave and the centre, and hence between the peripheral part of the scattered wave and the background. The phase difference so introduced can be described by $\beta(\theta/\theta_0)^2$, where β is the maximum phase difference at the periphery. The axial contrast is then given by solving the following modified form of equation (4*a*):

$$C'_{ph} = \frac{4\pi}{\lambda}\int_0^{\theta_0} I_\theta^{\frac{1}{2}}\theta \sin \beta(\theta/\theta_0)^2 d\theta$$

To evaluate this integral and others, it is necessary to know scatter distribution I_θ as a function of atomic number. There have been a number of theoretical derivations for this. Until recently, the data derived by Massey and Bullard[(7)] were typical; lately, however, doubt has been thrown on the validity of these data for small angles, and Lenz[(8)] has shown that, for angles less than 10^{-2} rad, the differential elastic cross-section should be less than the values given by the above authors by as much as an order of magnitude. Lenz derives an expression giving the differential cross-section as follows:

$$I_\theta = \frac{4}{a_H^2}\frac{Z^2}{(q^2 + 6Z/\Theta)^2} \qquad (5)$$

where $a_H = 0{\cdot}529$ Å (the Bohr radius)
$Z =$ the atomic number
$q = (4\pi/\lambda) \sin \theta/2$
$\Theta = \int_0^\infty \rho_r r^2 \times 4\pi r^2 dr$

ρ_r being the charge density distribution in the atom.

The variation of Θ for different energies and atomic numbers is not given specifically by Lenz; but the same quantity is present in an expression for the total cross-section which is evaluated in terms of the absorption thickness for films. This is shown in a graph (Fig. 2, Ref. 8) to be practically independent of atomic number and proportional to the electron energy (ϕ_0) up to 100 keV. From Lenz's graph, the value of Θ can be evaluated as follows:

$$6Z/\Theta = Z\lambda^2\phi_0/1{\cdot}4 \times 10^{-14}\pi a_H^2 \qquad (6)$$

For small angles, $6Z/\Theta$ is large compared with q^2; hence, I_θ is independent of angle and takes a value, obtained by substituting equation (6) in equation (5), which is also independent of atomic number and voltage:

$$I_\theta \simeq 10^{-15}\ \mathrm{cm}^2 \qquad (7)$$

The ratio of C'_{ph}/C_{ph} is not significantly affected by the choice of scattering data, and is independent of atomic number. Table 1 shows the variation of the ratio with β.

Table 1. *Variation of out-of-focus phase contrast with distance off focus*

β	C'_{ph}/C_{ph}
30°	26%
60°	52%
90°	70%
120°	78%
180°	51%

It is seen that practically all the phase contrast effect is obtained simply by defocusing. Furthermore, at least 50% of the full phase contrast can be obtained without defocusing by more than half the depth of focus. The sign of the contrast is, of course, reversed between one side of focus and the other. The distribution of intensity in the image could be obtained by the solution of equation (3), with the defocusing term $\sin \beta(\theta/\theta_0)^2$ inserted.

Table 2 shows the full phase contrast computed from equation (4*a*), both for the Massey–Bullard data and that of Lenz for 100 keV electron energy, the contrast being inversely proportional to the square root of the electron energy. From the Lenz data, the phase contrast becomes:

$$C_{ph} = 27{\cdot}6/d^2\,\%\ (d \text{ in Å})$$

The resolving power being defined by the well-known Abbe formula $d = 0{\cdot}61\lambda/\sin\theta$, or $d = 0{\cdot}61\lambda f/\rho_0$.

Table 2. *Variation of phase contrast with resolving power and atomic number*

	Z \ d(Å)	2	3	5	7	10
Massey–Bullard	4	14%	8%	3·7%	2·2%	1·2%
	16	21%	16%	7·2%	4%	2%
	64	(60%)	21%	13%	7·2%	3·4%
Lenz	All	6·9%	3%	1·1%	0·6%	0·3%

The evaluation with the Lenz data is more pessimistic than that based on the Massey and Bullard theory. It now appears that single atoms might only just be visible by phase contrast with a microscope giving a resolving power of 2–3 Å.

When considering a single atom, it is not of great importance to know the distribution of intensity in its image. It is more important to have an estimate of its possible visibility. When considering the imaging of an array of two or more atoms, the distribution of intensity is of the greatest importance. The problem of ascertaining such distributions will not be dealt with in this paper in detail, though certain simple extensions of the foregoing theory are worthy of note. If, instead of one atom, there are n atoms present, all within an area small compared with the resolving power (such as might be obtained with a row of atoms parallel to the axis of the microscope), the wave scattered into the aperture, and hence the contrast will be multiplied by n. If the area occupied by the n atoms is greater than that occupied by one atom, the contrast will only increase linearly with n so long as the total area is small compared with the resolving power. By the time this area equals the resolving power, the contrast will be about $0{\cdot}3n$ times that due to one atom. For larger areas, the contrast on the axis falls below $0{\cdot}3n_0$ times that due to one atom, where n_0 is the number of atoms within the resolved area, but an edge contrast of about $0{\cdot}3n_0$ times that due to one atom will be present.

AMPLITUDE CONTRAST

Any doubt about the accuracy of the previous assessments of amplitude contrast by the solution of equation (1) lies in the uncertainty of the area from which the energy falling on the aperture is missing in the image. To obtain this, it is required to know the distribution of intensity in the final image. The distribution of amplitude of the scattered wave in the final image is given by equation (3). The in-phase part of this (ψ_i) is obtained by multiplying by the sine of the unknown phase angle γ. The intensity distribution is then given by adding this to the background and squaring:

$$I_i = (1 - \psi_i' \sin \gamma)^2$$

The total energy in the image is then:

$$\varepsilon_i = \int_0^{R'} 2\pi R(1 - \psi_i' \sin \gamma)^2 dR$$

the integration being taken to some arbitrarily large value of R.

Clearly, the part contributed by $\gamma\psi_i'$ is that missing to the aperture, and, if this is a small fraction of the total the above integral yields:

$$\delta\varepsilon_i = \int_0^{R'} 4\pi R\psi_i' \sin \gamma dR = \int_{\theta_0}^{\pi/2} 2\pi I_\theta \sin \theta \, d\theta$$

The second integral is the fraction of the irradiating energy lost to the aperture. Substituting the value of ψ_i' from equation (3) with $\psi_0 = I_\theta^{\frac{1}{2}}/f$

$$\int_0^{R'} 4\pi R \sin \gamma \int_0^{\rho_0} \frac{2\pi I_\theta^{\frac{1}{2}}\rho}{f^2\lambda} J_0\left(\frac{2\pi\rho R}{f\lambda}\right) d\rho dR = \int_{\theta_0}^{\pi/2} 2\pi I_\theta \sin \theta d\theta \quad (8)$$

The solution of this equation gives $\sin \gamma$. Knowing this, the axial in-phase contrast C_a is given by:

$$C_a = \int_0^{\rho_0} \frac{2\pi I_0^{\frac{1}{2}}\rho}{f^2\lambda} \sin \gamma \, d\rho$$

$$= C_{ph} \sin \gamma$$

The solution of equation (8) is greatly simplified if $I_\theta^{\frac{1}{2}}$ is assumed to be constant inside the lens aperture, as is very nearly true.

The equation now becomes:

$$I_0^{\frac{1}{2}} \int_0^{R'} 4\pi R \sin \gamma \frac{\rho_0}{Rf} J_1\left(\frac{2\pi\rho_0 R}{f\lambda}\right) dR \doteq \int_{\theta_0}^{\pi/2} 2\pi I_\theta \sin \theta d\theta$$

or

$$2\lambda I_\theta^{\frac{1}{2}} \sin \gamma = \int_{\theta_0}^{\pi/2} 2\pi I_\theta \sin \theta d\theta$$

or

$$\sin \gamma = \left(\int_{\theta_0}^{\pi/2} 2\pi I_\theta \sin \theta d\theta\right) \Big/ 2\lambda I_0^{\frac{1}{2}}$$

Hence:

$$C_A = \left(\int_{\theta_0}^{\pi/2} 2\pi I_\theta \sin \theta d\theta \int_0^{\theta_0} \frac{4\pi I_\theta^{\frac{1}{2}} \sin \theta d\theta}{\lambda}\right) \Big/ 2\lambda I_0^{\frac{1}{2}}$$

If again $I_\theta^{\frac{1}{2}}$ is taken outside the second integral, a further error results, but it is partly compensatory to the previous one.

$$C_A = \int_{\theta_0}^{\pi/2} 2\pi I_\theta \sin \theta d\theta \Big/ (\lambda^2/\pi\theta_0^2)$$

Putting $\theta_0 = 0{\cdot}61\lambda/d$

$$C_A = \int_{\theta_0}^{\pi/2} 2\pi I_\theta \sin \theta \, d\theta / 0{\cdot}86 d^2 \quad (9)$$

which is not significantly different from the intuitive guess previously used [equation (1)].

Evaluation of the amplitude contrast from Massey and Bullard's data gives the following results for 100 keV electrons, the contrast now being inversely proportional to the voltage.

Table 3. *Variation of amplitude contrast with resolving pow and atomic number according to the Massey and Bullard da*

Z \ d(Å)	2	3	5	7	10
4	0·16%	0·09%	0·04%	0·02%	0·01
16	1·3%	0·55%	0·27%	0·15%	0·08
64	10%	4·7%	2·0%	1·1%	0·5%

A comparable figure can be evaluated from Lenz's data t expressing the amplitude contrast in the following form:

$$C_A = \left(\sigma_e - \int_0^{\theta_0} 2\pi I_0 \theta d\theta\right) \Big/ 0{\cdot}86 d^2$$

where σ_e is the total cross-section for elastic scattering whic is obtained from Lenz's results as $\sigma_e = 1{\cdot}36 \times 10^{-14} Z/\phi$ Putting $I_\theta = 10^{-15}$ (for θ_0 small), and $\theta_0 = 0{\cdot}61\lambda/d$, w obtain:

$$C_A = \frac{136Z - 1750/d^2}{0{\cdot}86 d^2 \phi_0} \ (d \text{ in Å}) \quad (1$$

The second term in this expression gives the loss of ampl tude contrast due to the scattered electrons which pas through the contrast aperture. These are only significant f very low atomic numbers, and high resolution; otherwis contrast varies inversely with d^2, and is proportional to Z It is in any case inversely proportional to ϕ_0. Table 4 show values derived from equation (10). These are, of course lower than obtained from the Massey and Bullard data.

Table 4. *Variation of amplitude contrast with resolving powe and atomic number, according to the Lenz data*

Z \ d(AU)	2	3	5	7	9
4	0·024%	0·038%	0·019%	0·010%	0·005%
16	0·44%	0·22%	0·08%	0·04%	0·02%
64	2·0%	0·94%	0·34%	0·18%	0·09%

EFFECT OF APERTURE SIZE ON CONTRAST

It will be noted that the predictions made all suggest that contrast will increase with increasing objective aperture. This is contrary to all experience in the electron microscope where any decrease in aperture results in improved contrast. This experimental observation is often explained as resulting from the increased collection of scattered electrons by the aperture. This would not be expected if the scattering distribution is as predicted by the theory. In that case, the value of $\int_{\theta_0}^{\pi/2} 2\pi I_\theta \sin \theta d\theta$ varies very slowly with θ_0 at values of θ_0 used. In fact, a large majority of the electrons scattered are already lost for a value of θ_0 corresponding to a resolving power of 3–4 Å. Variation of θ_0 would be expected to vary the amplitude contrast much more rapidly as a result of the corresponding variation in resolving power, in which case the contrast, according to equation (1), would vary as the square of the aperture angle.

In practice, the resolving power is limited by other factors, most of which are reduced, in effect, by reducing the aperture. Hence, the increase in contrast with reducing aperture probably arises because of the improved resolving power. There must, of course, be a limit to this process, but it is not easy to reduce the objective aperture indefinitely for mechanical reasons. In many types of specimen, the improve-ient in contrast with reduced aperture size may result from he improved resolving power obtained because of excessive ncoherent scatter.

ATOMS ON SUPPORT FILMS

In practice, it is not possible to support single atoms or mall aggregates in free space. It is therefore important to onsider whether such objects would be visible on a thin upporting film. In the absence of incoherent scattering, a erfectly uniform support film does not materially affect the bove contrast argument, which can indeed be applied to ocal irregularities in the support film.

EFFECT OF ABERRATIONS

As in light optics, the effect of aberrations could have been llowed for by insertion of the appropriate phase factors in he imaging integrals. For example, spherical aberration would require the addition of the phase factor $\sin S\,(\theta/\theta_0)^4$ n equation (3), where S is given by $S = \pi C_s\theta_0^4/2\lambda$, C_s eing the spherical aberration constant. It has been assumed n the discussion that the effect of aberrations can be neglected, s is true for spherical aberration if $\frac{1}{4}C_s\theta_0^4 < \frac{1}{4}\lambda$, where θ_0 s the limiting aperture angle.

EFFECT OF ILLUMINATING BEAM APERTURE

In order to take advantage of the all-important phase contrast effects described, it is necessary that the angular perture of the illuminating beam should be small compared with that of the imaging lens. If this is not so, it becomes mpossible to separate the background and scattered waves nd the phase contrast is lost. It will be appreciated, however, that a large fraction of the scattered wave is transmitted near the outer part of the aperture, simply because the area dded per unit increase in radius increases linearly with radius. For this reason, little of the predicted phase contrast should be lost when a comparatively large condenser aperture is used. Some gain may even result since the angular distribution of the scattered save will be flattened over an angle corresponding to that of the illuminating beam and will fall off less rapidly immediately outside this angle. It should be possible to utilize an illuminating aperture up to half or hree-quarters of the objective aperture without loss of contrast. This is important in view of the low intensity available in the electron microscope.

EFFECT OF VOLTAGE AND CURRENT STABILITY ON PHASE CONTRAST

Several criteria have been suggested to determine the maximum permissible high voltage and objective current ripple in the electron microscope. The present author has uggested this should be based on the necessity for keeping he focal plane corresponding to the photographic plate within the physical depth of focus of the objective lens. The physical depth of focus may be defined as the axial displacement of focus which leads to a 90° change in phase between the peripheral and axial parts of the imaging wave. This distance from focus is equal to $\lambda/2\theta_0^2$. Since this movement is allowed either side of focus, the physical depth of focus is λ/θ_0^2. The stability is now defined in the following expression:

$$\delta V/V - 2\delta I/I < \lambda/f\theta_0^2$$

or, putting $\theta_0 = 0{\cdot}61\lambda/d$, where d is the resolving power

$$\delta V/V - 2\delta I/I < (2{\cdot}7d^2/f\lambda)$$

Since the voltage and current fluctuations are, in general, independent, it was suggested that the individual criteria for $\delta V/V$ and $\delta I/I$ should be taken as:

$$\delta V/V < d^2/f\lambda$$

$$\delta I/I < d^2/2f\lambda$$

It will be seen from the foregoing discussion on phase contrast and out-of-focus phase contrast that it is not permissible to allow the focus to swing over a range of ±90°, as, in so doing, if the mean focus is the Gaussian one, the positive and negative phase contrast will cancel out, and, if a focus is chosen 45° off the Gaussian, some cancellation and some loss of resolving power will result. Thus, the swing must be reduced at least twice, and, if best use is to be made of the available contrast and resolving power, a reduction of more than four times is necessary. The new criterion is then:

$$\delta V/V - 2\delta I/I < 0{\cdot}7d^2/f\lambda$$

The individual criteria might then be taken as:

$$\delta V/V < 0{\cdot}3d^2/f\lambda \qquad (11)$$

$$\delta I/I < 0{\cdot}15d^2/f\lambda \qquad (12)$$

As an example, a resolving power of 5 Å with 100 keV electrons and an objective lens of focal length 0·3 cm, would require stabilities of about seven and four parts per million for the high voltage and lens current respectively.

CONTRAST DUE TO INELASTIC SCATTER

Electrons which lose an energy greater than about 0·3 eV in passing through the object are no longer coherent with the background or unscattered part of the transmitted beam. In addition, these electrons are not brought to the same focus as the elastically scattered ones because of the chromatic aberration of the imaging lenses.

This does not represent the total effect of the inelastic scattering, however: this is clearly so because the effect just described would give a positive contrast and this cannot exist without a compensating negative contrast. This negative contrast is, in fact, much more important than the above because it comes from a coherent wave. The coherent wave arises when the electrons are inelastically scattered to compensate for their loss from the coherent beam. This will be clearly understood if the scattered electrons are considered as first absorbed and then re-emitted with a smaller energy. The absorption process is represented at each point by a reduction in the amplitude of the illuminating beam. Thus, over the scattering area, the illuminating beam is reduced in amplitude. If, as before, the amplitude is made up to recreate the uniform wave, and this is compensated by an equal antiphase vector distribution over the scattered area, the latter will clearly give a scattered wave in antiphase with the background wave. The contrast due to this scattered wave can be calculated as for the phase contrast, except that no phase change need now be introduced.

Let it be assumed that the area over which the inelastic scattering takes place in a single atom comprises a disk of radius r_0, and that the probability of scatter is uniform over this disk. The problem is then to calculate the effect of a scattered wave of amplitude (ψ_s) when it arrives in the image after traversing the objective aperture.

The intensity of the coherent wave immediately behind the scattering atom will be $(1 - \sigma_{in})/\pi r_0^2$, where σ_{in} is the total cross-section for inelastic scattering. The amplitude of the scattered component of this is given by:

$$\psi_s = 1 - [(1 - \sigma_{in})/\pi r_0^2]^{\frac{1}{2}}$$

$$\sigma_{in}/2\pi r_0^2$$

Proceeding as before, the amplitude distribution in the aperture plane is given by:

$$\psi_\rho = \int_0^{r_0} \frac{2\pi\psi_s r_0}{f\lambda} J_0\left(\frac{2\pi r\rho}{f\lambda}\right) dr$$

$$- \psi_s r_0 J_1\left(\frac{2\pi r_0 \rho}{f\lambda}\right)$$

$$= \frac{\sigma_{in}}{2\pi r_0} J_1\left(\frac{2\pi r_0 \rho}{f\lambda}\right)$$

The amplitude of the scattered wave at the Gaussian image point is then:

$$\psi_{i0} = \int_0^{\rho_0} \frac{2\pi\psi_\rho \rho}{f\lambda} d\rho$$

$$= \frac{\sigma}{2\pi r_0^2}\left[1 - J_0\left(\frac{2\pi r_0 \rho_0}{f\lambda}\right)\right]$$

Or, putting $\rho_0/f = \alpha_m$ and $0{\cdot}61\lambda/\alpha_m = d$

$$\psi_{i0} = (\sigma/2\pi r_0^2)\ [1 - J_0(10r_0/d)]$$

The contrast given by this scattered wave is given by:

$$\begin{aligned} C_{in} &= 1 - (1 - \psi_{i0})^2 \\ &\simeq 2\psi_{i0}^2 \\ &= (\sigma_{in}/\pi r_0^2)[1 - J_0(10r_0/d)] \end{aligned} \tag{14}$$

To evaluate this, the value of r_0 is required. There is no direct information concerning this value in the scattering calculations. One is tempted to relate it to the cross-section, but it must be remembered that the cross-section is not strictly an area, but a probability. The most pertinent value of r_0 is the radius of the outermost electron shell in the atom since it is known that this shell contributes most to inelastic scatter. For this purpose, r_0 can be given the value quoted in Lenz's paper [equation (30)] which, for 100 keV, gives:

$$r_0 = 0{\cdot}9Z^{-\frac{1}{3}}\,(\text{Å})$$

Thus

$$C_{in} = 0{\cdot}39\sigma_{in}Z\ [1 - J_0(9/dZ^{\frac{1}{3}})] \tag{15}$$

(σ_{in} and d are in Å).

Lenz [equation (56), Ref. 8] gives the inelastic cross-section as:

$$\sigma_{in} = \frac{\lambda^2\Theta}{3\pi a_H^2} \log \frac{6Z}{\bar{q}^2\Theta}$$

where θ has the same value as for elastic scattering. $\bar{q} = \pi J/2\lambda e\phi$, where J is the ionization potential of the atom. Since this only occurs within the logarithm, it is sufficient to give it an approximate value. Putting in the value of Θ and $J = 10$ eV, and evaluating, gives:

$$\sigma_{in} = 3600/\phi_0\ (\text{Å})^2$$

Thus

$$C_{in} = \frac{1400Z}{\phi_0}[1 - J_0(9/dZ^{\frac{1}{3}})] \tag{16}$$

Results computed from this expression are tabulated in Table 5.

Table 5. *Variation of contrast due to elastic wave fr inelastic collisions as a function of resolving power and atom number*

Z \ d(Å)	2	4	8
4	5·6%	1·8%	0·4%
16	7·1%	1·8%	0·4%
64	7·1%	1·8%	0·4%

FOCUSING OF INELASTICALLY SCATTERED ELECTRONS

The electrons which are scattered inelastically are, aft scattering, distributed over angle and velocity. If it is assume that the distribution with angle is independent of that wit velocity, an expression can be derived for the total distributio after making certain assumptions about the velocity distr bution which has not been specifically derived.

The angular distribution (differential cross-section I'_θ) ca be obtained from Lenz's equations (52) and (36),[(8)] whic give:

$$I'_\theta = \frac{4Z}{a_H^2 q^4}\left[1 - \frac{1}{(1 + q^2\Theta/6Z)^2}\right]$$

$$\Theta = 2{\cdot}64 \times 10^{-13} a_H^2/\lambda^2\phi_0$$

and q for inelastic scattering is given by Lenz's equation (4

$$q = \frac{2\pi}{\lambda}\sqrt{\left(\theta^2 + \frac{J}{4e\phi_0}\right)}$$

For vanishingly small angles, the distribution becomes:

$$I'_\theta = 1{\cdot}4 \times 10^{-13}\phi_0/J^2$$

For larger angles, the dependence is:

$$I'_\theta = 8{\cdot}8 \times 10^{-15}/\phi_0\theta^2$$

These two expressions can be combined to give a simple a sufficiently accurate expression to cover all angles from 0 t the maximum relevant in the electron microscope:

$$I'_\theta = 8{\cdot}8 \times 10^{-15}\phi_0/(6{\cdot}3 + \phi_0^2\theta^2) \qquad (17$$

in which J has been given the value of 10 eV.

If it is assumed that the distribution with velocity o energy is Gaussian with a mean width of $e\phi_m$ electron volt (i.e. width at which the amplitude is reduced to $1/e$), the tota distribution can be expressed by:

$$I_{in}d\phi_l = \frac{10^{-14}\phi_0}{6{\cdot}3 + \phi_0^2\theta^2} \exp{(\phi_l/\phi_m)^2} d\phi_l \qquad (18$$

The constant is here adjusted so that on integrating over al values of ϕ_l, the total number is unity. This expression give the fraction of all electrons falling on a square centimetr which are scattered by one atom into unit solid angle θ, an having velocity loss between ϕ_l and $(\phi_l + d\phi_l)$.

The imaging of the inelastically scattered electrons ca now be considered. Consider Fig. 3: A is the objectiv aperture subtending a semi-angle θ_0 at the image (unity magnification), B is the Gaussian image plane, and C the plane of focus for electrons with energy loss ϕ_l. The axia distance between the planes at B and C is $z = C_c(\phi_l/\phi_0)$, where C_c is the chromatic aberration constant for the lens. The electrons with loss between ϕ_l and $\phi_l + \delta\phi_l$ can be considered as arising from a point source at C. The intensity due to these at a point radius R in the Gaussian plane is given by $I_{in}d\phi_l/z^2$.

The total intensity and the contrast (C'_{in}) at the point in estion is then given by:

$$C'_{in} = \int \frac{I_{in}}{z^2} d\phi_l$$

tting in the value of I'_{in} from equation (18)

$$= \int_{z=R/\theta_0}^{\infty} \frac{10^{-14}\phi_m\phi_0 \exp - (\phi_l/\phi_m)^2}{(6\cdot 3 + \phi_0^2\theta^2)z^2} d\phi_l/\phi_m$$

tting $\phi_l = z\phi/C_c$, $\theta = R/z$ and re-arranging, gives:

$$= \frac{1\cdot 6\times 10^{-15}\phi_0^3}{\phi_m C_c^2} \int_{z=R/\theta_0}^{\infty} \frac{\exp - (z\phi_0/\phi_m C_c)^2}{(z\phi_0/\phi_m C_c)^2 + (\phi_0^4 R^2/6\cdot 3\phi_m^2 C_c^2)} d\frac{z\phi_0}{\phi_m C_c} \tag{19}$$

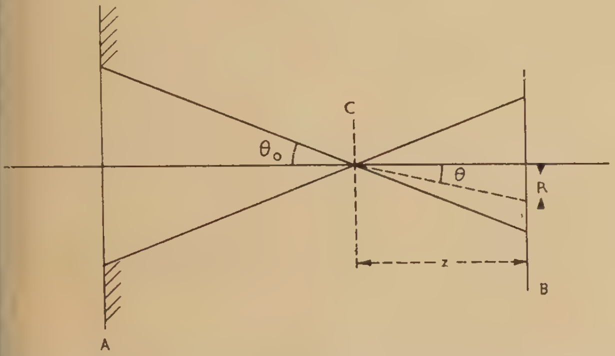

Fig. 3. Ray diagram illustrating the derivation of the expression for the distribution of inelastically scattered electrons

This expression is approximate in that it assumes an finitely small size for the resolved spot. As a result, the tegral value goes to infinity as $R \to 0$. This difficulty is ercome by limiting the minimum value of R to a value ual to the instrumental resolution. The soundness of this ep is easily apparent. After doing this, evaluation of the rms in the denominator of equation (19) shows that the st term is always negligible. The explanation of this lies the fact that this term sets the value of the angular scatter tensity at very small angles, and not only are the small gle scattered electrons little affected by chromatic aberration, but also they are comparatively few in number because ey occupy relatively less area near the axis than those thin the same angular range far from the axis. The pression then simplifies to a simple probability integral, e solution of which gives:

$$C'_{in} = 9 \times 10^{-15}\frac{\phi_m}{R^2\phi_0}\left(1 - \frac{R\phi_0}{\theta_0\phi_m C_c}\right)$$

The accuracy of this expression is adequate provided the acketed term is greater than $0\cdot 3$. For smaller values, the curacy falls off and the integral should be evaluated from bles of the probability function.

Putting $\theta_0 = 0\cdot 61\lambda/d$ where d is the resolving power:

$$C'_{in} = 9 \times 10^{-15}\frac{\phi_m}{R^2\phi_0}\left(1 - \frac{1\cdot 6Rd\phi_0}{\lambda\phi_m C_c}\right) \tag{20}$$

The contrast on the axis is given by putting $R = d$ (the solution). The distribution of the defocused disk will be ven with reasonable accuracy by:

$$C'_{in} = 9 \times 10^{-15}\frac{\phi_m}{(d^2 + R^2)\phi_0}\left[1 - \frac{1\cdot 6d(d + R)\phi_0}{\lambda C_c\phi_m}\right]$$

Putting in typical values $\phi_m = 10$ V, $\phi_0 = 100$ kV, $C_c = 0\cdot 4$ cm, the results for the maximum contrast due to the inelastically scattered electrons shown in Table 6 are obtained:

Table 6. *Variation of contrast due to inelastically scattered electrons with resolving power*

d (Å)	3	5	10
C'_{in}	0·1%	0·036%	0·001%

It is seen that the contrast due to the inelastically scattered electrons is very small compared with that due to other causes. This, in itself, justifies the approximation of the derivation. However, it will be realized that, for extended objects, the blurred "patches" of electrons from each resolved object point will overlap and build up a contrast which, in the limit, will just cancel the negative contrast due to the missing part of the illuminating wave. Thus, the contrast due to inelastic scattering will only occur in small detail, or at edges or discontinuities in extended objects. In this respect, it is similar to phase contrast.

CONCLUSIONS

It has been shown that the overall contrast mechanism in the electron microscope can conveniently be divided into four parts, the in-phase or amplitude, and the quadrature or phase contrast, due to the elastic scattering from the nucleus, the contrast arising from the elastic wave scattered from the illuminating wave, where a gap or depression is left by the inelastically scattered electrons, and that due to the inelastically scattered electrons themselves.

The magnitude of the four effects have been calculated, and the second and third are shown to predominate and be of roughly equal importance. Using the scattering data due to Lenz,(8) it is found that an electron microscope with the highest attainable resolution (2–3 Å) should be capable of making single atoms visible.

Extension of the simple theory applied should allow a more detailed analysis to be made for more complex types of object than here considered.

ACKNOWLEDGEMENTS

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Two optical instruments used in semiconductor research

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A single-prism monochromator and a light-spot microscope are described. The monochromator, aperture *f*3, is intended for low resolution work, and employs a Littrow-mounted prism and a single lens. Typical figures for scattered light intensities at various wavelengths are given. The light-spot microscope, which uses a reflecting objective, provides a spot of light which can be as small as 10 μ in diameter. The spot can be positioned accurately on the semiconductor surface with the aid of two micrometer adjustments; the whole area around the spot is visible through the microscope whilst the instrument is in use.

This paper describes a simple, single-prism, *f*3 monochromator, and a "light-spot" microscope using purely reflective optics, which have been used for some time past in studies of optically induced effects in germanium,(1) silicon, indium antimonide(2, 3) and other semiconductors(4) at this Establishment.

MONOCHROMATOR

In many studies of optical effects in semiconductors, a source of radiation of variable wavelength is useful. Examples are determinations of spectral distribution of photo-effects, and studies of apparent variations in carrier diffusion length with incident wavelength in the light-spot experiment.(5) In many cases, high resolution is not required, but rather as large an amount of energy as possible within a bandwidth of a few tenths of a micron.

A monochromator designed to meet this requirement is shown in outline in the figure. The Littrow-mounted prism used is the same as those used in the Leiss double monochromator(6); the calcium fluoride prisms at present in use have an apex angle of 31°, a base length of 70 mm, and a height of 50 mm. Prism rotation is effected *via* a worm drive, by a dial and calibrated screw head, angular measurement of 1′ of arc being possible.

Three fixed slit widths (0·5, 1, and 2 mm) are available for entrance and exit slits, arranged radially on a plate which may be turned to bring any slit into position; a spring-loaded lock holds it in place. Both entrance and exit slit plates are mounted inside nuts which give some back-and forth focusing adjustment.

To save space, a fluorite lens system is used rather than mirrors. The lens is mounted on a slide, and a calibrated screw enables the lens to be set at the correct focal distance from the slits for any particular wavelength. It may be noted that for bandwidths greater than 0·1 μ, this adjustment has very little effect on the energy output. The lens system comprises a meniscus and a bi-convex lens and was designed for the instrument by Barr and Stroud Ltd., who also computed its focal length over the whole wavelength range from 0·4 to 8 μ. It is arranged so that its axis bisects the angle between the central entrance and exit rays at the mid-point of its travel. Its diameter is 50 mm, and its focal length varies from 117 mm at 0·4 μ to 150 mm at 8 μ. The useful *f*-number of the instrument varies from 2·7 to 3·4.

The whole optical arrangement is contained in a cast light alloy box, the outside dimensions of which, including lid, are 29 × 11·5 × 13·5 cm. It has mounting feet such that the plane of the instrument as shown in the figure can be arranged to be either horizontal or vertical.

Using a tungsten lamp with a periclase window as source(7) and 0·5 mm slits, the bandwidth at 1 μ is 0·35 μ, and at 5 μ is 0·2 μ. At 5 μ, with 0·5 mm slits, the ratio of useful radiation to scattered light using a thermocouple detector, at least 160/1. The instrument thus serves as a useful "filte of appreciable aperture to isolate various spectral regions interest in semiconductor work, and is a convenient ar versatile tool for any infra-red work where high resolution not required.

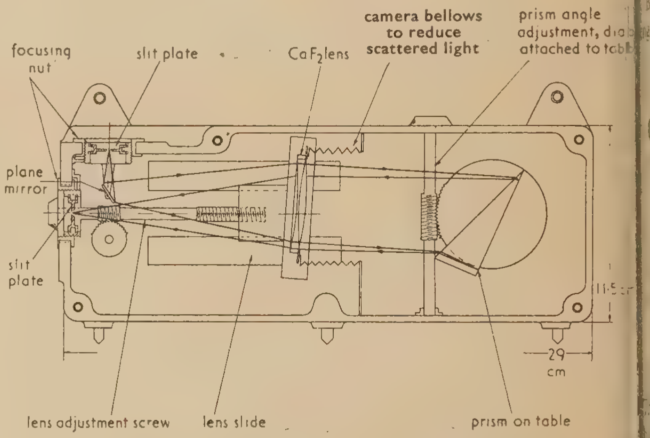

Diagram of single-prism monochromator

LIGHT-SPOT MICROSCOPE

Many of the experiments on semiconductors require light spot of very small size and precise geometrical shape Apart from the now classical light-spot experiment,(8) smal illuminated areas can be used as emitters in the Haynes-Shockley type of experiment, or to study local variations i surface conditions by observing variations in photo-effects An apparatus to produce such light-spots, apart from providing spots of defined geometry with dimensions down t approximately 10 μ, should have facilities for varying th spot size, for precisely locating it on a crystal surface, fo viewing the crystal whilst the experiment is in progress, and for handling light over a wide wavelength range to be usefu for a wide variety of semiconductors.

An instrument meeting these requirements has been designed using reflecting optics only. A number of apertures of suitable shape and size are cut into a disk which can be rotated to bring any particular aperture on the axis of the system. This aperture is illuminated from an external source (e.g. the monochromator described above) and a reflecting objective provides a diminished image of the aperture on the specimen surface. The demagnification is ×15, and the smallest images so far employed have been a rectangle measuring 15 × 300 μ, and a circle of diameter 10 μ. These dimensions have been measured using visible light, but for larger wavelengths diffraction effects may increase the image e, since the numerical aperture of the system is only 0·28. tween the apertures and the objective the light is reflected rough 90° at a half-silvered plate, and an eyepiece is ranged with its focal plane coincident with the image of e specimen surface formed by light transmitted through the ate. In this way the surface of the specimen, together th the light spot, can be viewed directly during an experient, and, furthermore, very little light of wavelengths eater than 1–2 μ is lost, since the half-silvered plate becomes almost perfect reflector in the infra-red region.

The specimen is mounted on a table which can be moved der the microscope with micrometer adjustments, so that e position of the centre of the light spot can be determined within $\pm 1\ \mu$ in two perpendicular directions.

The table and movements are sufficiently robust to allow a suitably designed vacuum vessel to be mounted on e table so that light-spot experiments can be carried out ith specimens at low temperature in a vacuum.

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Operation of a diffusion cloud chamber with 23 atm of deuterium

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The successful operation of an 18 in. diameter diffusion cloud chamber filled with deuterium at a pressure of 23 atm is reported. The importance of the tritium and oxygen content are discussed. An account of the apparatus for the manufacture and transfer of the deuterium is given.

he diffusion cloud chamber has been used with success in gh energy nuclear physics for a study of the interactions tween elementary particles, especially those involving the roduction of π-mesons. The main advantage of this pparatus over the expansion cloud chamber is that it is ntinuously sensitive when filled with light gases at high ressure. This makes it suitable for operation with ccelerators such as the Birmingham proton synchrotron, hich provides a pulse of 1000 MeV protons every ten conds. The use of such a chamber in conjunction with the nchrotron, when filled with hydrogen at a pressure of 5 atm, has already been described.(1)

The cloud chamber has now been operated successfully at pressure of 23 atm of deuterium. This paper describes the urce and production of the deuterium, and operating nditions for satisfactory chamber performance. Since the mount of vapour available for track formation in a diffusion amber is limited, the presence of quite small amounts of itium may seriously affect the performance because of its dioactivity. A hydrogen-filled diffusion cloud chamber as been used(2) to measure the tritium content of ordinary ater, from which the hydrogen is produced chemically.

APPARATUS

The cloud chamber(1) has a volume of fifty litres and an perating pressure of about 300 lb/in.^{2} was intended. Since euterium is not available commercially in England it was ecessary to produce it in the laboratory. Fig. 1 illustrates e apparatus for its manufacture, storage and transfer. The euterium was obtained by electrolyzing 99·5% heavy water, roduced at Norsk Hydro, Norway, and purchased through the Atomic Energy Research Establishment, Harwell. Electrolysis was considered the method most likely to result in the production of pure deuterium. The electrolyte used was caustic soda at an initial concentration of 3%. This would result in a hydrogen content of at most 1% in the deuterium. The use of Na$_2$O$_2$ was not possible because of the slow evolution of oxygen.

The cells, one of which is shown in Fig. 1, are enlarged versions of one in use on a similar but smaller apparatus at the

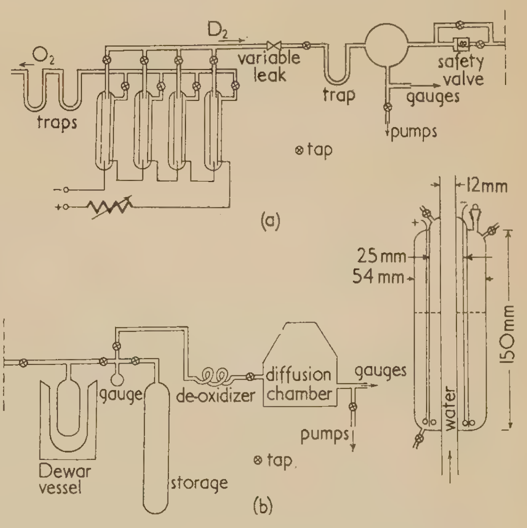

Fig. 1. (*a*) Deuterium generator and (*b*) storage vessels

Clarendon Laboratory, Oxford. Each was made from two coaxial glass tubes, with the heavy water inlet and drain and the outlet for the oxygen in the outer tube (54 mm diameter), and the outlet for deuterium at the top of the inner tube (25 mm diameter). The inner tube is supported in the outer one with a small (2 mm) clearance at the bottom for the ion current. The electrodes are helices of nickel wire mounted close to and one each side of the inner tube 2 mm from its end, supported from tungsten–glass seals at the top of the cell. A third central tube, 12 mm in diameter, is used for water cooling. Smooth operation is obtained for currents up to about 8 A, the resistance of each cell being about 3 Ω. Sheet nickel electrodes were much less satisfactory because of the formation of large bubbles of gas. The oxygen passed to the atmosphere through two liquid air traps, one to remove atmospheric moisture and the other to collect heavy water lost from the quite warm cell. A further trap was placed between the outlet for the deuterium and the pumps and storage vessels.

The deuterium was collected continuously in a Vibrac steel cylinder of four litres capacity (by Vickers Armstrongs Ltd.), filled with activated charcoal, and immersed in a large Dewar vessel filled with liquid air. A variable leak permitted the deuterium pressure in the cell to be maintained near atmospheric pressure, fine control being obtained by varying the current through the cell. If the cylinder was filled to atmospheric pressure when cold, and sealed, a pressure of about 900 lb/in.^{2} was obtained at room temperature. The deuterium was then transferred to the storage cylinder (30 l.) and the process repeated. About 1050 g of heavy water were electrolyzed, the process taking about a hundred hours. It was therefore necessary to ensure that the air leak rate into the system was low. The charcoal was degassed at 300° C for twelve hours and the heavy water pumped for several minutes to remove all air before electrolysis was commenced. Glass and metal taps and vacuum and pressure gauges allowed control of the apparatus.

Deuterium was transferred to the cloud chamber and back with the assistance of the activated charcoal. The chamber was carefully evacuated and the deuterium inserted slowly through a spiral of copper tubing four feet long packed with copper granules and maintained at a temperature of 400° C. This ensured the removal of all oxygen, the importance of which is mentioned below. The constitution of the gas was investigated in the Chemistry Department of the University with a mass spectrometer. Initially it was found to contain 94·9% D_2, 3·1% HD, 0·35% N_2 or CO, 0·06% O_2, and small amounts of methyl alcohol and water vapour. The HD percentage was unaltered after a hundred hours operation of the cloud chamber. This confirmed the absence of any exchange reaction between the hydrogen atoms in the CH_3OH molecule, and the deuterium, a fact previously established by heating a sample mixture to 160° C for sixteen hours.

OPERATION OF THE CLOUD CHAMBER, AND DISCUSSION

A theory of the diffusion cloud chamber has been given by Shutt,$^{(3)}$ and it is essentially in agreement with experiment. Shutt has shown that the temperature gradient dT/dx required for successful operation depends only on a parameter β, which is related to μ_0 the viscosity of the gas at 0° C, D_0 the diffusion coefficient of the vapour within the gas at N.T.P., P the gas pressure, n_0 the number of ions per cm^2 per second which would be produced in air at N.T.P. by the radiation within the chamber, τ the number of atoms per molecule of the gas, and Z its atomic number. The equatic for β is, for temperatures below about 260° K,

$$\beta = \mu_0 D_0^{-1/3} P^{1/3} [n_0 \tau z P + f(t)]^{4/3} \qquad ($$

where $f(t)$ is a function of the temperature t of the vapo source, and takes account of the removal of vapour by t growth of droplets on large molecular aggregates of meth alcohol. The assertion that dT/dx depends only on β ha been verified experimentally by Bevan$^{(4)}$ for a variety gases under various conditions in a particular chamber.

The maximum temperature of the vapour source for goo performance is set by the fact that instability of the ga vapour mixture occurs when the density of the mixture the source exceeds that near the top of the sensitive laye The chamber is then no longer uniform, but sensitive patches. To ensure the best sensitive depth and shorte flash delay times, it has been the practice to operate at ten peratures as close to this limit as possible. Care is necessar for during a long experiment the settings of the heate elements on the chamber wall are dependent upon ambien conditions. These vary considerably because of the pulse magnet in which the chamber is located.$^{(1)}$ The main para meters for good operation with both hydrogen and deuteriu are summarized in the table. These are typical approximat values used during an experiment. The temperatures which instability occurs, 30 and 45° C respectively, ar rather lower than those calculated,$^{(4)}$ but differ by appro mately the calculated amount.

Operating parameters at 24 atm

	Hydrogen	*Deuteriu*
Maximum source temperature (°C)	30	45
Source temperature (°C)	22–25	38–42
Base temperature (°C)	−55	−50
Sensitive depth (cm)	6·0	4·5
Temperature at top of sensitive depth (°C)	−17	−15
n_0 (ions cm^{-3} s^{-1})	5	14
dT/dx (°C/cm)	6·4	7·9
$3{\cdot}3 \log_{10} \beta + 8{\cdot}2$ (°C/cm)	7·1	9·8
Flash delay time (s)	0·12	0·20

The table shows that a sensitive depth noticeably less tha that for hydrogen, but nevertheless satisfactory, has bee obtained with deuterium. The quality of the tracks is eviden from Fig. 2, which is a photograph showing a beam o 950 MeV protons from the synchrotron. The large numbe of blobs of ionization is due to the decay electrons of mea energy about 8 keV from the tritium present in the gas These are the main reason for the higher values of dT/dx an source temperature used for deuterium. Satisfactory opera tion with deuterium has not been achieved at the sourc temperature used for hydrogen. The effect of the facto $\mu_0 D_0^{-1/3}$ is relatively small, and for the purpose of this pape the term $f(t)$ has been neglected. The value for this ter used by Bevan is approximate and it is not evident from hi communication to what extent his empirical relation $dT/dx =$ $3{\cdot}3 \log_{10} \beta + 8{\cdot}2$ (°C/cm) depends on $f(t)$. At the sourc temperature of 40° C used for deuterium, his expression fo $f(t)$ suggests that it would easily be the larger term i equation (1), whereas it is evident in practice that althoug the background is important, this is not so.

For cosmic radiation the value generally used for n_0 is two Further, about fifteen high energy proton tracks and th associated background are passed through the chamber eac ten seconds; these are equivalent to a further 3 ions cm^{-2} s n air at N.T.P. In the case of deuterium about 800 tritium ecays are found on each photograph. Assuming each emains visible for 1·5 s, the number of decays per cubic entimetre per second is about 0·065, and the corresponding umber of ions is nine. Since it is known that the use of eam intensities several times greater than mentioned results n local vapour depletion, causing gaps in tracks as well as a ubstantial reduction in the sensitive depth, it is evident that he tritium decays will influence chamber performance coniderably. The values of β for hydrogen ($n_0 = 5$) and leuterium ($n_0 = 14$) are 0·45 and 2·95, the ratio of the actors $\mu_0 D_0^{-1/3}$ being 0·62 only. The corresponding values of dT/dx according to Bevan are 7·1 and 9·8° C/cm whilst he values used were 6·4 and 7·9° C/cm respectively. The differences in source temperature used arise from the lifferences in dT/dx. Thus the chamber performance with leuterium can be approximately accounted for by the theory. A higher temperature gradient is required for deuterium ecause of the lower sensitive depth, but cannot be achieved ecause of the limit to the source temperature.

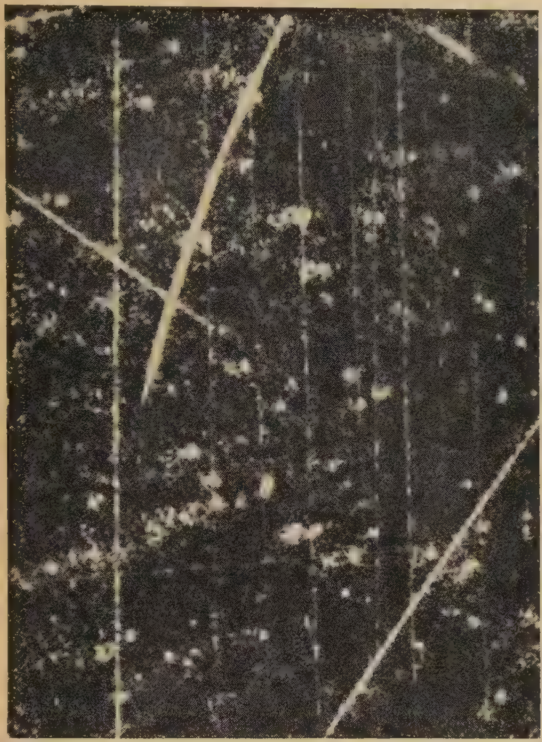

Fig. 2. Typical photograph showing 950 MeV proton tracks and background blobs due to tritium decays

To obtain a better sensitive depth with deuterium it would e necessary to use a gas with a substantially lower tritium oncentration. The ratio T/H in ordinary rain water in Norway is about 10^{-18},(5) although it may be considerably higher elsewhere.(6) In producing 99·5% D_2O from ordinary water by electrolysis, as is done at Norsk Hydro, the tritium ratio T/D is expected to increase to about 5×10^{-14}.(5) For 0·065 decays per cubic centimetre per second and a half-life of 12·4 years the observed concentration may be shown to be $3{\cdot}0 \times 10^{-14}$, in reasonable agreement with that expected. For lower concentrations the use of very old heavy water, or glacial water with a lower initial tritium content,(2) would be necessary. Less tritium would also result in improved photographs, for the blobs of ionization cause gaps in the tracks owing to local vapour depletion, and also by their presence may occasionally result in uncertainty in the interpretation of events.

A longer flash delay time than that normally employed for hydrogen is necessary to obtain satisfactory photographs in deuterium (see the table). Hazen(7) has shown experimentally with expansion chambers that for a given degree of supersaturation for nitrogen and hydrogen, the rate of increase of surface area of a drop is approximately proportional to the diffusion coefficient of the vapour in the gas. In the present case the ratio of the flash delay times used is not inconsistent with the ratio of the coefficients D_0, which is 1·66. There is, in addition, the effect of local vapour depletion just mentioned.

The initial oxygen content in the deuterium was 0·06%. The pulsed magnetic field applied to the cloud chamber is quite non-uniform, and, moreover, changes in uniformity as the field strength increases to its maximum value of 13 kG. This causes gas motions as a result of the paramagnetism of the oxygen, and, for the concentration stated, velocities of about 1 cm/s may be achieved. These make the measurement of track curvature quite impossible. It is, therefore, essential to remove all traces of oxygen from the deuterium as described above. No evidence for significant gas motions has been observed with commercial hydrogen stated to contain not more than ten parts per million of oxygen. These observations emphasize the need to evacuate the cloud chamber thoroughly before the insertion of any gas. The question of accurate momentum measurements in a diffusion cloud chamber is discussed by Culwick(8) in another paper.

A study of the interaction of 950 MeV protons with deuterons is in progress, and will be reported elsewhere. Since this paper was written, two preprints describing experiments with diffusion chambers filled with deuterium to a pressure of 17 atm have been received. L. M. Lederman, K. C. Rogers and R. Rockmore of the University of Columbia have investigated the scattering of 85 MeV positive pions in deuterium,(9) and V. P. Kenney of the Brookhaven National Laboratory has studied meson production in deuterium by 1400 MeV negative pions.(10)

ACKNOWLEDGEMENTS

We are grateful to Prof. P. B. Moon for his interest in this work, and to Prof. Sir Francis Simon for advice on the deuterium generator. Dr. J. C. Robb has been kind enough to analyse several samples of deuterium. Two of us (A. P. B. and B. B. C.) wish to thank the Department of Scientific and Industrial Research for maintenance grants, and one of us (H. B. K.) is indebted to Norges Teknisk Naturvitenskapelige Forskningsraad for a research grant, and to J.E.N.E.R., Norway, for a year's leave of absence.

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A constant-current device for use in the measurement of transference numbers by the moving-boundary method

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A circuit is described which will supply a current of between 0·5 and 2·5 mA, constant to 0·1%, with a ten-fold load impedance change, in the range 5–500 kΩ.

For an investigation of transference numbers by the moving-boundary method⁽¹⁾ a current source of up to 2·5 mA was required which would be constant to 0·5% or better over a ten-fold load impedance change in the range 5–500 kΩ. Other workers⁽²,³⁾ who have only had to contend with much smaller changes in load impedance have used a battery-operated single pentode circuit. The circuit to be described is similar in general design to the simpler circuit used by Spiro and Parton.⁽⁴⁾

THE CIRCUIT

The circuit is shown in Fig. 1; its operation may be described briefly as follows. Current passes from the negative of a 400 V power supply through the monitoring element (RV_2 and R_{10}), through the current control circuit (V_4, V_5, V_6) and finally through the load and measuring device to the positive of the power supply. The potential developed across the monitoring resistance is fed to a cathode-coupled amplifier circuit (V_1, V_3) where it is amplified and compared with a steady potential derived from a discharge-tube (V_2). The resulting difference-potential is fed from the anode of V_3 to valves V_4, V_5, V_6 which control the constancy of current through the load. The sensitivity of the amplifier circuit is increased by the use of positive (regenerative) feedback, stability being maintained by the inclusion of V_3 in the negative feedback loop formed by the control circuit and monitoring resistance.

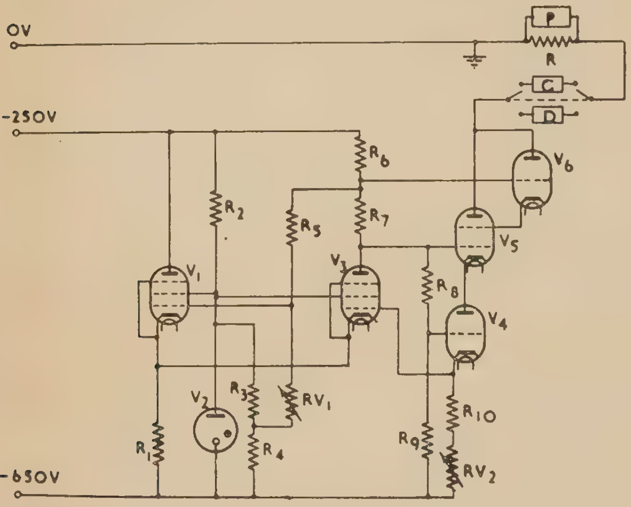

Fig. 1. Circuit diagram of constant-current device

V_1 = SP61
V_2 = VR105/30
V_3 = EF86
V_4, V_6 = 6J5GT
V_5 = KT44T (CV1576)
RV_1 = 500 kΩ
RV_2 = 25 kΩ

R = 100 Ω
R_1 = 15 kΩ w.w.
R_2 = 68 kΩ w.w.
R_3 = 100 kΩ w.w.
R_4 = 10 kΩ w.w.
R_5 = 10 MΩ carbon
R_6, R_8 = 2 MΩ carbon
R_7 = 330 kΩ carbon
R_9 = 250 kΩ carbon
R_{10} = 3·3 kΩ w.w.

RV_2 is the current control which may be varied to give currents between 0·5 and 2·5 mA. RV_1 is the stabilization control and a position can be found on this potentiometer for which an increase or decrease in load resistance produces no appreciable change in current.

The chief difference between the present device and that used by Spiro and Parton⁽⁴⁾ lies in the current control circuit which provides for higher operating voltages and an extended working range. Positive feedback amplifiers tend to be markedly non-linear, hence it is desirable to restrict their working range as far as possible. By improving the sensitivity of the control circuit the amplifier output required to cover the working range is less than if a relatively inefficient triode were used, with better linearity over a larger working range.

Current was measured to 0·1 μA by the drop across a 100 Ω standard resistance R with the potentiometer circuit P. Grounded positive operation was used in order that the potentiometer circuit may be near earth potential to reduce the risk of electrical leakage within it. The device was allowed a preliminary warming-up period on a dummy load D. Connexion between this and the moving-boundary cell C was made by a double ceramic switch of the "make-before-break" type.

The circuit was constructed initially from war-surplus material but was later rebuilt. In Fig. 1 modern valve types

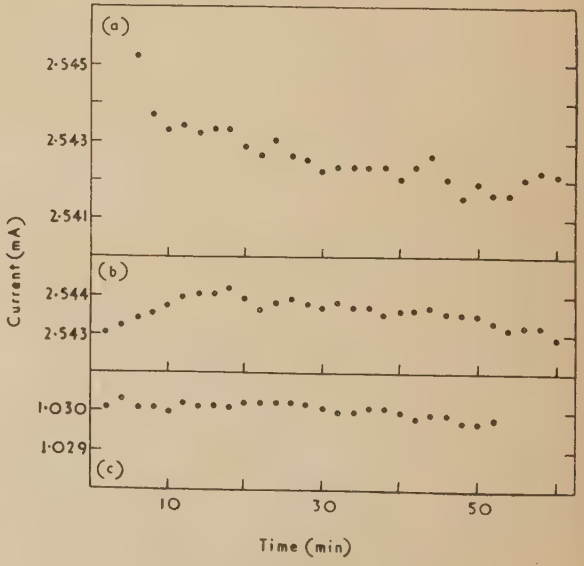

Fig. 2. Performance of circuit

(*a*) Stability from warm-up on constant load of 20 kΩ.
(*b*) Stability with steady load change of 5–50 kΩ.
(*c*) Stability with steady load change of 25–250 kΩ.

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* Now at the Mosul Petroleum Co., Ain Zalah, Mosul, Iraq.
† Now at Associated Electrical Industries Ltd., Aldermaston, Berkshire.

e given except in the case of V_5 where no equivalent valve is ailable. The requirements for V_5 are g_m as high as possible, fairly high with a screen grid to operate at +25–50 V ove the cathode for a current of 2 mA with $\mu > 500$.

PERFORMANCE AND STABILITY

By measuring the maximum resistance required for the rcuit to depart from linear operation at different currents was found that about 500 V are available for the cell *C*.

The 400 V power supply (unstabilized) was derived from a onventional power-pack with π-filter. A 1% change in ains voltage produces a 0·1% change in load current. The urrent through the load is directly proportional to the grid-athode potential of V_1 and ultimately on its cathode emission. mall fluctuations in heater current despite the use of a onstant-voltage transformer on the mains-input cause some ight variation in the output current. The use of positive edback in the amplifier renders it very sensitive to dis-urbance of this type. The variation of current from the me of switching on at a constant load is shown in Fig. 2(*a*). he variation of current with steady load changes of 5–50 kΩ nd 25–250 kΩ is shown in Fig. 2(*b*) and (*c*), from which it seen that the overall variation of current was less than 0·1% ver these ranges. In consistent use the variation in current ver the full resistance change was rarely more than 0·1%.

CONCLUSIONS

The circuit described gives very satisfactory performance for the present purpose. The circuit is of application in many fields of work where a small constant current source is required. With suitable modification (to V_4, R_{10}, RV_2), however, the circuit could be made to operate up to 50 mA but with some loss in available volts.

ACKNOWLEDGEMENTS

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A bent crystal X-ray spectrograph

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[*Paper received* 16 *July*, 1956]

Details of the principle and construction of a new design of bent crystal spectrograph of the transmission type are described. Different possible settings of the instrument with respect to the X-ray beam are discussed and advantages over the previous designs pointed out.

ent crystal spectrographs of both transmission and reflexion ypes are now widely used in the field of X-ray spectroscopy. he origin of this important spectroscopic tool can be traced o de Broglie(1) who indicated that a curved crystal may be eveloped as an alternative to a plane oscillating crystal in ne study of X-ray spectra. Darbord(2) also made similar eferences to the use of bent crystals. In 1916 Gouy(3) dis-ussed the focusing properties of curved crystals. It was, owever, not until 1930 that the focusing properties of the urved crystals were actually utilized in the construction and evelopment of bent crystal spectrographs when Du Mond nd Kirkpatrick(4) developed a multicrystal spectrograph in reference to a single bent crystal instrument. Spectrographs f the reflexion type were also devised by Johann(5) and ohansson.(6) In 1932 Mlle Y. Cauchois(7,8) designed a ingle bent crystal spectrograph and used it successfully in er extensive researches in X-ray spectroscopy. Mlle auchois showed that if a divergent broad beam of mono-hromatic X-rays emerging from an X-ray tube window is ransmitted through a sheet of crystal bent into the form of a ylinder, focused spectra are obtained on the concave side f the cylinder over the surface of another cylinder which is angential to the crystalline cylinder and whose diameter is qual to the radius of the latter.

Generally in such spectrographs, the arrangements for etting up the crystal and for mounting the film are somewhat inflexible, so that mechanical difficulty in seeing that the focusing condition is satisfied is inevitable. Moreover, in the usual spectrographs there is considerable difficulty in setting the crystal holder for the desired Bragg angle and recording the higher order spectra. In designing and constructing the bent crystal spectrograph described here not only are the above defects removed, but focusing of the lines over a more or less extended range is readily obtained by using a curved film holder which is capable of backward and forward motion along a line perpendicular to the axis of rotation of the arm carrying the cassette. The crystal used in this instrument is a thin sheet of muscovite mica held in a crystal mount.

PRINCIPLE

Figs. 1, 2, 3 and 4 show the geometry of the system. Let a set of atomic planes having the lattice constant d belonging to a certain zone axis make an angle α with the normal to the cleavage plane of mica. When the crystal is bent cylindrically to a radius of curvature R for the particular zone axis, these planes intersect approximately on a cylinder called the *focal cylinder* which is tangential to the crystalline cylinder and whose radius is $\frac{1}{2}R$. The dotted line CP is the trace of an atomic plane passing through the centre of the crystal aperture and making an angle α with the normal CN through that point. Now in order that for a particular wavelength λ the Bragg equation $2d \sin \theta = n\lambda$ may be satisfied the incident beam CQ must make an angle θ with CP. Obviously then, the crystal normal CN must be turned through an angle either $|\theta - \alpha|$ or $(\theta + \alpha)$ about C. Figs. 1–4 represent the different possible settings of the spectrograph for different values of θ. In these settings the portion of the incident beam limited by the aperture of the crystal and converging at Q will be brought to focus at F after reflexion from the set of planes making an angle α with the normal to the cleavage surface. NF subtends an angle $2(\theta + \alpha)$ or $2|\theta - \alpha|$ at the centre of the focal circle for $|\theta - \alpha|$ and $(\theta + \alpha)$ settings respectively.

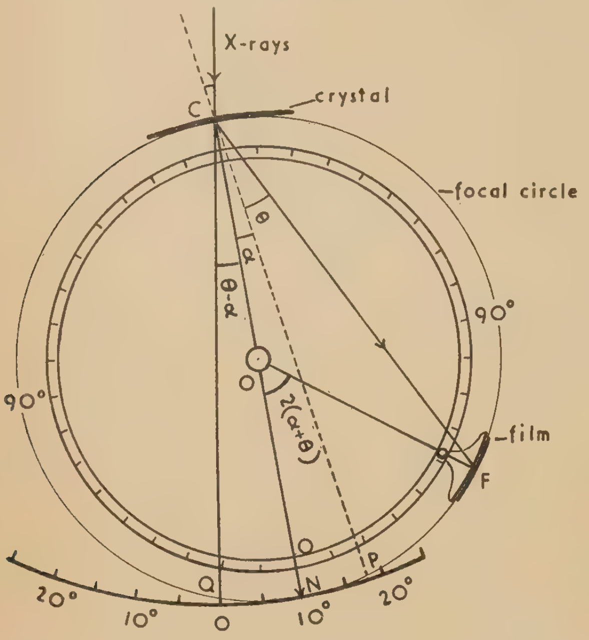

Fig. 1. Setting of spectrograph for $(\theta - \alpha)$ with $\theta > \alpha$

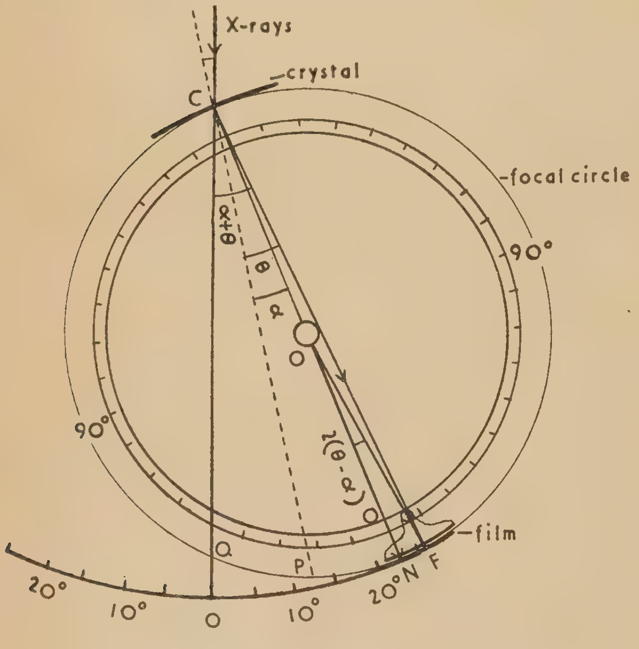

Fig. 2. Setting of spectrograph for $(\theta + \alpha)$ with $\theta > \alpha$

DESCRIPTION

Fig. 5 is a view of the spectrograph designed and constructed in our laboratory workshop. It consists of a triangula brass plate g_1 resting on three levelling screws s. The bas of the plate is machined to a circular arc which is divide into a scale q_1 reading to half a degree, with its centre situated at c. This scale is marked up to 25° on both sides of its middle point m. There is a similar brass frame g_2 which is capable of sliding over two circular rails r fixed on the base plate, about the cone joint at c. The upper frame can be clamped to the base plate by means of the screw s_1 and its

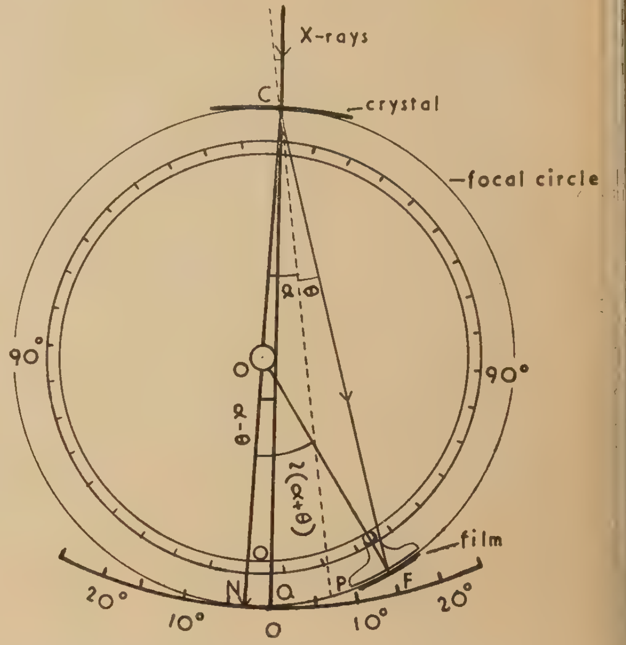

Fig. 3. Setting of spectrograph for $(\alpha - \theta)$ with $\theta < \alpha$

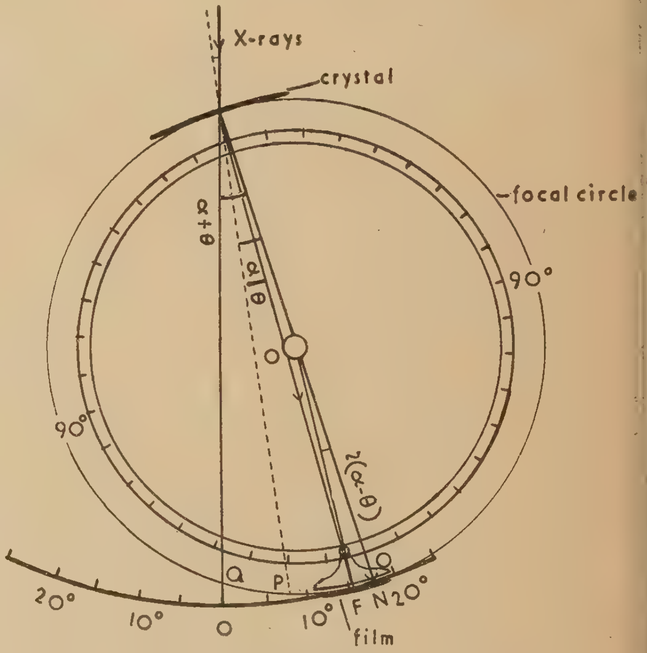

Fig. 4. Setting of spectrograph for $(\alpha + \theta)$ with $\theta < \alpha$

osition can be read on the scale q_1 by the pointer p_1. A ircular gunmetal rim having its centre at *o*, at a distance 0 cm from *c*, is fixed on the upper frame by means of screws. The whole of this rim is provided with a scale q_2 divided to alf a degree.

The crystal holder *h* consists of two brass blocks accurately rofiled to cylindrical surfaces (one being convex and the ther concave) of radius of curvature 40 cm. A well-tested muscovite mica sheet, suitably oriented along a particular zone axis is held between the blocks. A rectangular aperture *a*, 20 × 5 mm, at the centre of the blocks allows the crystal surface to be exposed to the X-rays. The pressure on the crystal sheet is adjusted by means of the screws s_2. The crystal holder is held firmly on two circular brass blocks *b* by means of guide pins attached to the blocks. The position of these blocks is adjusted very accurately so that the two ends of the crystal holder are equidistant from *o*.

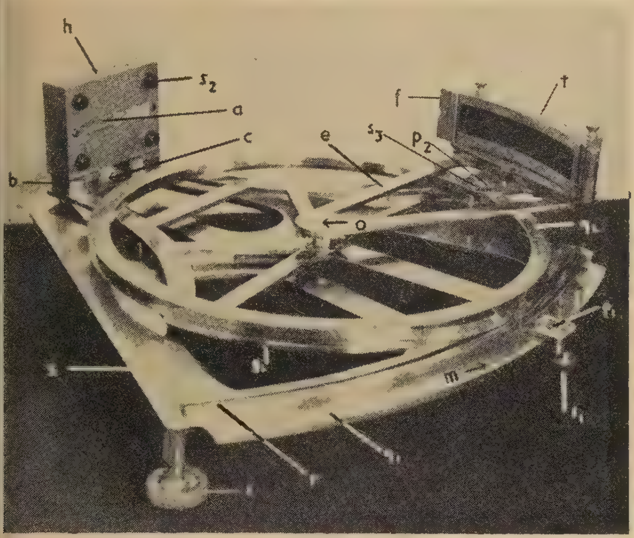

Fig. 5. View of the bent crystal spectrograph

The arm *e* carrying the film cassette *f* can be rotated about *o* and is capable of being clamped to the circular rim in any desired position by the screw s_3. The pointer p_2 denotes the position of the film cassette on the scale q_2. The platform *t* which holds the film cassette can be moved along a line perpendicular to the axis of rotation of the arm *e* by means of a screw (not visible) on the reverse side of the platform. This platform can hold either a plane or a curved cassette as required. After a few trials the platform can be adjusted for recording very sharp spectral lines on the plate or film placed in the cassette.

SETTING

After mounting the crystal in the holder, the spectrograph as a whole is placed so that the X-ray beam passes normally through the crystal aperture, the pointer p_1 being in the zero position. The inclination of the spectrograph is adjusted by the levelling screws so that the intense portion of the beam as seen on the fluorescent screen is at the same height as the cassette from the circular rim. Now, for a particular wavelength λ to be studied, the values of θ and α are obtained from the knowledge of the lattice constant of the reflecting planes of mica and the dimensions of the unit cell. The pointer p_1 is turned through an angle $|\theta - \alpha|$ or $(\theta + \alpha)$ on the scale q_1 and the arm *e* carrying the cassette is turned through an angle $2(\theta + \alpha)$ or $2|\theta - \alpha|$, as the case may be. Figs. 1, 2, 3 and 4 represent the four possible settings of the spectrograph for a particular set of planes.

PERFORMANCE

We have very successfully used mica as a crystal in our spectrograph for the study of X-ray emission and absorption spectra. The main difficulty is with the choice of a good sample which is free from warping, air holes and other surface defects. After several trials one can get a good sample which gives very sharp spectral lines. The intensity of the spectra due to a particular set of planes varies from sample to sample. We have come across some samples which give an intense (100) reflexion but a very weak ($\bar{2}01$) one. A detailed report on the use of mica in a curved crystal spectrograph will appear elsewhere.

The accuracy of profiling the crystal holder is one of the factors which governs the sharpness of the spectra. Our blocks were first accurately machined to the radius of curvature of 40 cm on a precision lathe. They were then very carefully ground together for perfect fitting with each other. It was observed that a slight change of pressure on the crystal sheet caused much distortion of the spectral lines, thus showing the necessity for exercising extreme care in mounting the mica sheet between the cylinders of the crystal mount. When mounted with care and managed skilfully, mica gives sharp straight spectral lines. It may be worth noting that Watson(9) has reported a number of serious drawbacks in using mica as a diffracting crystal in bent crystal spectrographs and had to reject it in favour of quartz. In our extensive study of the X-ray emission and absorption spectra of rare earths we have seen that very reliable spectrograms were obtained by well chosen and carefully mounted mica crystals in the spectrograph described here. We have used this instrument up to 2·5 Å but attempts are being made to adapt the spectrograph for use in a softer region and an account of this will be given later.

In some investigations we have used a mica sheet successfully by holding it to the convex block only by rubber bands. The use of the second block is necessary when a thick and stout crystal is to be mounted in the holder.

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A linear, temperature compensated hot-wire anemometer

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A hot-wire anemometer is described which gives a linear output over the range of wind speed 1 to 16 m/s and is therefore well suited to studies of atmospheric turbulence. It is also provided with temperature compensation so that the effects of air temperature fluctuations (both rapid and slow) are eliminated. These desiderata are achieved with little increase in complexity over the simple hot-wire circuit.

For convenience and accuracy in the use of hot-wire anemometers in studies of atmospheric turbulence there are two desirable characteristics not found in the usual arrangement employed in wind-tunnel work. These two features, (i) compensation for air temperature fluctuations, and (ii) linearity of calibration, are especially desirable in meteorological work because of the large magnitude of the temperature and velocity fluctuations. The circuit to be described here fulfils these requirements in a simple manner. Linearity is secured by using a germanium crystal rectifier as a circuit element, the non-linear resistance characteristic of which counteracts that of the hot wire. Other non-linear circuit elements have been used in the past [e.g. fine platinum wires in still air(1) and thermionic valves(2)] but the germanium crystal rectifier has advantages of simplicity and stability.

TEMPERATURE COMPENSATION

Compensation for air temperature fluctuations is effected by using two hot wires close together, the wires being in adjacent arms of a suitable Wheatstone bridge circuit. In Fig. 1, R_1 and R_2 are the two hot wires which are of the same diameter but of differing length, e.g. R_2 twice as long as R_1. The currents through the hot wires are maintained very nearly constant by making R_3, $R_4 \gg R_1$, R_2.

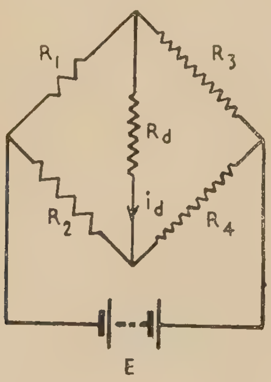

Fig. 1. The bridge circuit with hot wires R_1 and R_2, the compensating wire (R_2) being of the order of twice the length of R_1

The rate of change of hot wire resistance R with changing air temperature may be obtained as follows. From the proportionality of heat loss to temperature excess of the wire

$$i^2R = c(T_w - T_a) \qquad (1)$$

where i is the hot wire current, T_w and T_a are temperatures of wire and air, and c is a function of the air speed and density. Also

$$R = R_0(1 + \alpha T_w) \qquad (2)$$

R_0 being the resistance of the wire at 0° C and α the temperature coefficient of resistance of the material of the wire. Eliminating T_w from equations (1) and (2) gives

$$R = \frac{cR_0(1 + \alpha T_a)}{c - i^2R_0\alpha} \qquad (3)$$

which, with i and c taken to be constant, may be differentiated to yield

$$\frac{dR}{dT_a} = \frac{cR_0\alpha}{c - i^2R_0\alpha} = \frac{\alpha R}{1 + \alpha T_a} \qquad (4)$$

For the bridge arrangement of Fig. 1 with R_3, $R_4 \gg R_1$, R_2 and a low resistance battery arm, the current i_d through the detector arm is given, to a close approximation, by

$$i_d = \frac{E(R_1R_4 - R_2R_3)}{R_3R_4(R_d + R_1 + R_2)} \qquad (5)$$

Applying equation (4) to the two hot wires R_1, R_2 and using equation (5) gives

$$\frac{di_d}{dT_a} = \frac{\alpha E(R_1R_4 - R_2R_3)}{R_3R_4(R_d + R_1 + R_2)(1 + \alpha T_a)} \qquad (6)$$

which shows that with the bridge balanced, so that R_1, $R_4 = R_2$, R_3, the compensation would be exact. However, the bridge is in balance at only one air speed; at others the compensation is imperfect but still very much better than with a one-wire bridge for which the numerator in equation (6) would be αER_1R_4, the denominator remaining unchanged.

In practice there are other imperfections in compensation owing to simplifications introduced in the above theory. The hot-wire and compensator-wire currents are not strictly constant and also equation (2) is only approximate for platinum, the material commonly used for the wires. For a given change in air temperature, the change in resistance of both wires is somewhat less than indicated by equation (4) and this effect is greater for the hot wire R_1 than for the cooler compensating wire R_2. The result is a slight over compensation at all speeds as may be seen from column (*b*) of the table. Comparison of column (*b*) with column (*a*) shows the marked improvement of the constant current two-wire bridge over a simple uncompensated arrangement.

Variation of galvanometer reading with air temperature at two air speeds using (a) *a simple hot-wire bridge*, (b) *constant current two-wire bridge*, (c) *as* (b) *but with shunted compensator*

Wind speed (*m/s*)	*Air temperature* (°*F*)	*Galvanometer reading* (*cm*)		
		(*a*)	(*b*)	(*c*)
1·15	70	3·8	2·30	2·25
1·15	80	2·9	2·55	2·30
1·15	90	2·0	2·75	2·35
15·60	70	13·4	13·2	14·35
15·60	80	12·65	13·3	14·30
15·60	90	11·7	13·4	14·25

The temperature compensation of the two-wire bridge may be further improved [as shown by column (*c*) of the table] by shunting the compensating wire with a fixed resistance to reduce the effective α of the combination. The best value of his shunt resistance is found empirically and in this way it s possible to reduce the error in the measurement of air speed o about 0·3% per °C air temperature change over the range 1 to 16 m/s. The corresponding figure for an uncompensated hot wire is about 4% per °C.

A merit of the two-wire bridge is the near equality of the time constants of the hot wire and compensator ensuring compensation for the rapid turbulent fluctuations of air temperature as well as for the slower diurnal changes. There is some loss in sensitivity as the effects of the two wires are opposed but the loss is small as the longer wire operates at a much lower temperature than the other.

LINEARIZATION

Linearization is achieved by inserting a non-linear circuit element in the detector branch of the bridge circuit. Germanium crystal rectifiers were found to have a current/voltage characteristic suitable for this purpose. The logarithm of the current passed by the rectifier increases linearly with applied potential difference up to about 0·2 V and thereafter less rapidly. Other rectifiers (selenium, etc.) have similar characteristics but are inferior in stability. Because of its large temperature coefficient of resistance, it is necessary to maintain the germanium rectifier at constant temperature and this may conveniently be done by keeping it immersed in ice and water in a Dewar flask. Stirring was found to be unnecessary. Under these conditions a typical variation of rectifier resistance with applied potential difference is as follows:

potential difference (V)	0·06	0·12	0·18	0·24	0·30
resistance (kΩ)	35	13·5	4·9	2·2	1·3

The circuit finally adopted is shown in Fig. 2 and a specimen calibration in Fig. 3, together with the calibration before linearization for comparison.

With R_5 and R_7 (Fig. 2) small compared with R_d, the resistance of the rectifier, and R_6 large, from equation (5) the potential difference across the rectifier is approximately given by

$$e_d = \frac{E(R_1R_4 - R_2R_3)}{R_3R_4} \cdot \frac{R_5}{R_5 + R_1 + R_2}$$

so that, for a given wind speed range, R_5 determines the range of potential difference across the rectifier. Variation of the bridge balance by means of the shunt across R_4 enables this range of potential difference to be applied to a suitable part of the rectifier characteristic.

The bridge voltage E should be such that with R_8 small compared with R_3, the hot-wire current is about 0·08 A for 0·0005 in. diameter platinum wire or 0·2 A for 0·001 in. wire.

Adjustment of the circuit proceeds as follows. With $R_6 \simeq 50\ \text{k}\Omega$, $R_7 \simeq 50\ \Omega$ and the bridge balanced for a wind speed near the lower end of the working range, approximate linearization is first achieved by variation of R_5 and the shunt to R_4. A final adjustment to the slopes of the lower and upper regions of the calibration curve may then be made by varying R_6 and R_7 respectively. This ability to control separately the upper and lower parts of the curve is a useful feature of the arrangement.

As R_7 must be small compared with the rectifier resistance for the characteristic of the combination to be suitable for linearization (particularly so for a large air speed range), it follows that the output potential difference developed across R_7 (180 μV per m/s in the present example) is small compared with that given by a simple hot-wire bridge, i.e. linearization

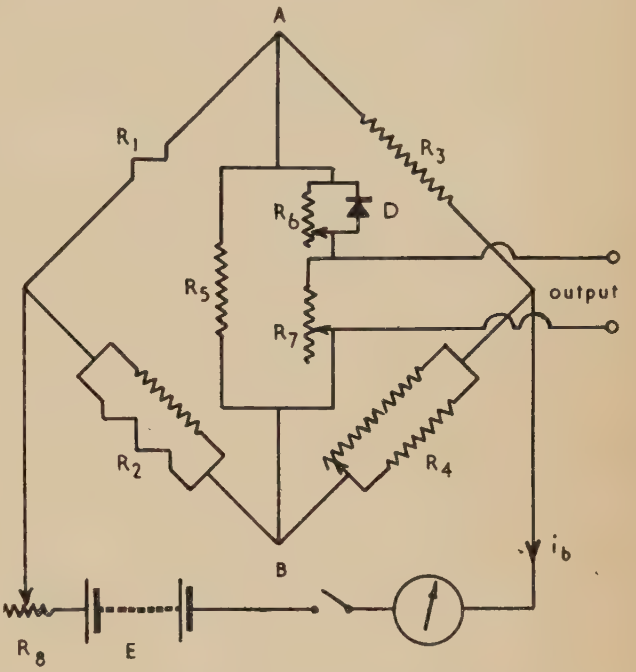

Fig. 2. The circuit of the linearized, temperature-compensated hot-wire anemometer

R_1 = 5 cm of platinum wire, diameter 0·0013 cm
R_2 = 10 cm of platinum wire, diameter 0·0013 cm shunted by 600 Ω
R_3 = 500 Ω
R_4 = 650 Ω with variable shunt of 0·1 MΩ
R_5 = 60 Ω
R_6 = 26 kΩ
R_7 = 100 Ω
$R_8 \simeq$ 20 Ω such that i_b = 0·15 A at lower end of range (1 m/s)
D = germanium crystal rectifier type GEX34 (by General Electric Co. Ltd.) held at 0° C
E = 50 V

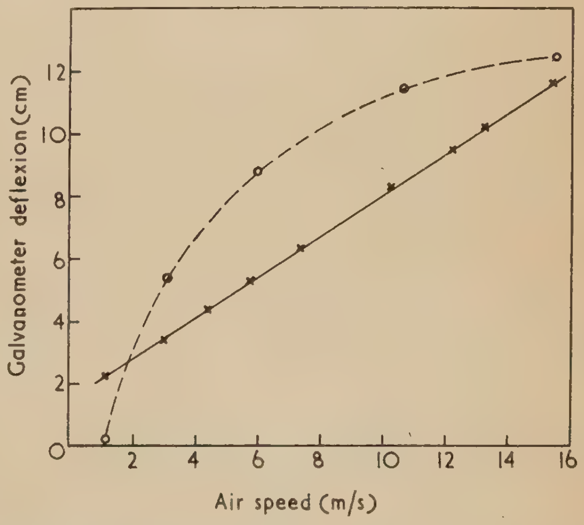

Fig. 3. Specimen calibration of the linearized, temperature-compensated hot-wire anemometer (full line) together with that of unlinearized arrangement (broken line) for comparison

is achieved at the expense of sensitivity. However, for most purposes, the drawback of reduced sensitivity is outweighed by the advantages of linearity.

The design is reasonably flexible, and as an example an alternative set of circuit values suitable for 0·001 in. platinum wire and a 12 V accumulator are given below.

$R_1 = 2{\cdot}3$ cm of platinum wire, diameter 0·0025 cm
$R_2 = 4{\cdot}6$ cm of platinum wire, diameter 0·0025 cm, shunted by 60 Ω
$R_3 = 50\ \Omega$, $R_4 = 70\ \Omega$ with variable shunt of 1 kΩ
$R_5 = \infty$, $R_6 = 150\ \text{k}\Omega$, $R_7 = 610\ \Omega$, $R_8 \simeq 1\ \Omega$.

With the bridge balanced at 3 m/s this arrangement gives a linear a calibration as that shown in Fig. 3 and over the same range of wind speed. The output is 360 μV per m/s.

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Measurement of high viscosities by shearing between parallel plates

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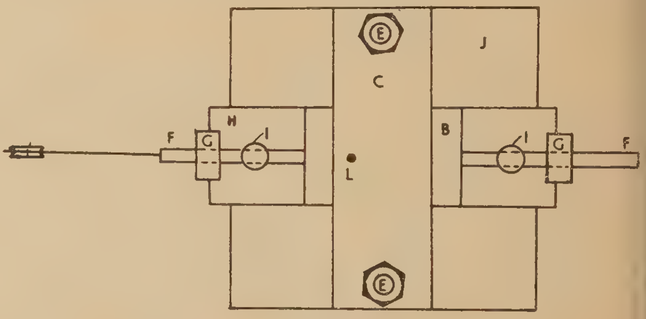
Viscosities in the range 10^4–10^7 poises have been measured by shearing thin films between two parallel stainless steel plates. In this way frictional heat is rapidly dissipated, temperature being registered by a thermistor.

It is frequently required to study the flow properties of pastes and solutions with a high solids content, of which the viscosity may be up to 10^7 poises. Conventional rotation methods, or falling sphere techniques are not always practicable, due, among other things, to filling difficulties. Furthermore, heating the substance to assist filling is not always a satisfactory procedure since, as with concentrated tannin solutions, with which we are mainly concerned, irreversible changes occur above 50° C. Another complication may arise if the paste is hygroscopic leading to large changes in viscosity as with tannins; it is then necessary to ensure that exposed surfaces are reduced to a minimum. It is also important that any heat generated during shearing shall be rapidly dissipated, and that the temperature at which the measurement is made shall be reasonably accurately known.

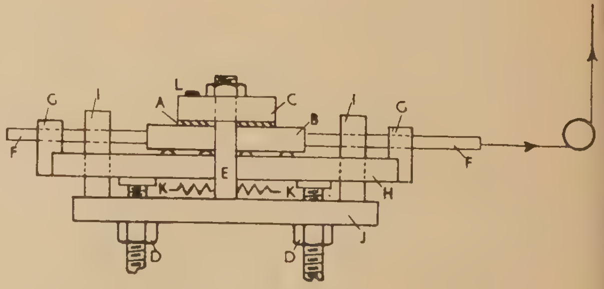
The method described below, in which a thin film of the material is sheared between two parallel stainless steel plates overcomes all these difficulties. By using this method we have studied the viscosity of a number of concentrated tannins over a range of temperatures.*

DESCRIPTION OF THE APPARATUS

Fig. 1 shows the elevation and plan of the apparatus. The sample *A* in the form of a thin film approximately 1 in. square is introduced between two rectangular steel plates B and C 1 in. wide, set at right angles to each other. The thickness of the film can be adjusted by means of locking screws *D*. The upper plate *C* is rigidly located on the pillars *E*, whereas the lower plate *B* is free to move in a direction parallel to its major axis, and at right angles to that of the stationary plate *C*. The movement of *B* working through rods *F* and guides *G* is controlled by a simple weight and pulley mechanism. Friction is reduced to a minimum by a ball bearing mounting *H*. The gap between *B* and *C* may be set with the aid of a feeler gauge by adjusting the locking screws *D* under the mounting *H* which can slide vertically during adjustment on two supports *I*. The assembly is mounted on a base plate *J*.



(*a*)



(*b*)

Fig. 1. Plan (*a*) and elevation (*b*) of viscometer

The whole apparatus stands on levelling screws in a water-tight Perspex box placed in a water thermostat. A small heater *K* (2–3 W) located under the moving plate enables the sample to be brought rapidly to the experimental temperature,

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* While preparing this paper it was noted that the July issue of *Analytical Chemistry* gave a description of a microviscometer embodying the same principle as this instrument. Labout and Oort. *Analyt. Chem.*, **28**, p. 1147 (1956).

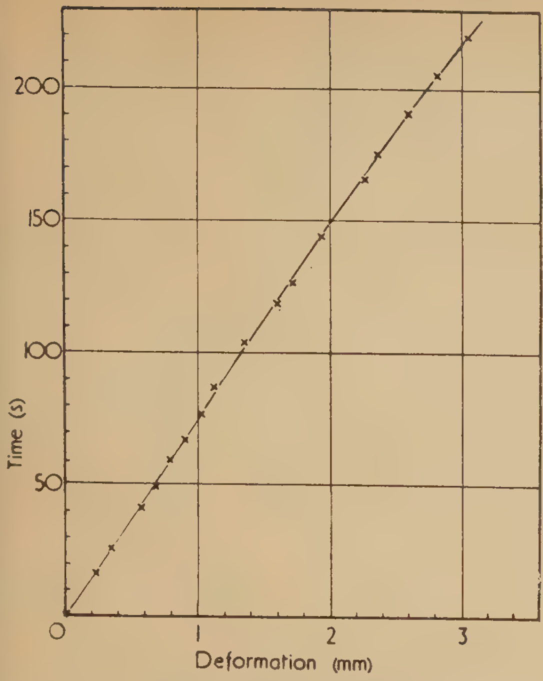

Fig. 2. Typical deformation-time characteristics obtained for a mimosa tannin

hich is measured by means of the bead type thermistor *L* ounted on the fixed plate. This was calibrated in the usual ay. In this way a reproducibility of ±0·01° C was obtained in the temperature measurement. An optical lever system enables the deformation to be followed during an experiment.

EXPERIMENTAL PROCEDURE

The gap was set to a predetermined value and a small pellet of the sample was placed on the lower plate *B*, the upper plate *C* being removed; *C* was then screwed down to its supports. In this way a film of the sample, approximately 1 in. square, was obtained. Any excess was cut away from the edges of the plates with a spatula. The whole was then transferred to the Perspex box in the thermostat and the temperature of the sample brought rapidly to the required value by the heater *K*. Appropriate loads were then applied and deformation-time characteristics followed from the light scale readings from which viscosity is calculated.

Deformation-time curves show that the moving plate rapidly reaches a constant velocity lasting approximately until the sample shears through 0·25 cm, after which the sample breaks down at the edges and the velocity increases. A typical deformation-time curve is shown in Fig. 2.

For Newtonian fluids the viscosity η in poises is given simply by, Wa/Au, where W is the load in dynes, a the plate gap in cm, A the area under shear in cm^2, and u the constant velocity attained in cm s^{-1}. Plasticity diagrams may be constructed since the shearing stress is given by W/A and the rate of shear by u/a.

ACKNOWLEDGEMENT

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A portable ionization current comparator

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A self-contained and portable version of the Kemp ionization current comparator is described in practical detail. The instrument employs a single sub-miniature electrometer valve (run from Mallory dry cells) in a null circuit, together with a taut-suspension reflecting galvanometer system, which is built-in. From the direct-reading linear scale, the ratio of one ionization current to the other may be read off as a percentage of the initial value obtaining for this ratio in a series of experimental readings. The instrument has many applications in radiological work, in which a separate radiation monitor would otherwise be necessary in order to eliminate the effects of X-ray intensity fluctuations. Observations with an accuracy better than 1% can be made with ease.

The basic principles, and many of the practical applications, f this instrument, have been described in a series of papers lsewhere.(1–8) An outline only of the theory will therefore e given here, the main purpose of the present paper being o describe in detail a new, self-contained and particularly ompact form of the instrument. A general view is shown n Fig. 1. The outside dimensions of the containing box are 6 × 10 × 12 in. high.

OUTLINE OF THEORY

Consider Fig. 2. Essentially the instrument consists of two onization chambers *P* and *Q* arranged to collect charges of opposite signs, and connected to the opposite ends of a capacity potential divider C_1 and C_2, at least one component of which, e.g. C_2, is variable, the junction of the two capacities being connected to a sensitive potential-indicating device such as the grid of an electrometer valve, or the needle of a Lindemann electrometer. Normally the earthing key k_3 is opened first, followed by the simultaneous operation of k_1 and k_2. (For the purpose of checking a balance once obtained, it is advantageous to reverse this order of operation.) The rationale of this key sequence is discussed in the earlier publications.(1,2,4,8) The balance is obtained by adjusting the variable capacity C_2 until the junction of the capacities C_1 and C_2 remains at earth potential as the chamber charges

Q_1 and Q_2 accumulate. This condition is indicated by a null deflexion of the detecting system. It has been shown$^{(8)}$ that the balance is quite unaffected by the (fixed) charges induced on the system by the chamber batteries B_1 and B_2.

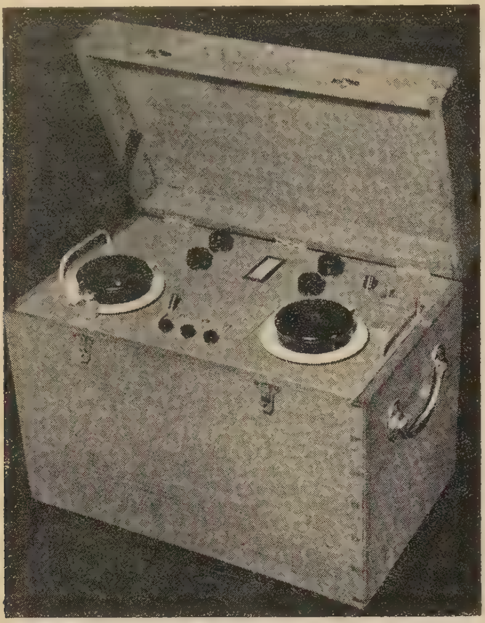


Fig. 1. General view of portable comparator

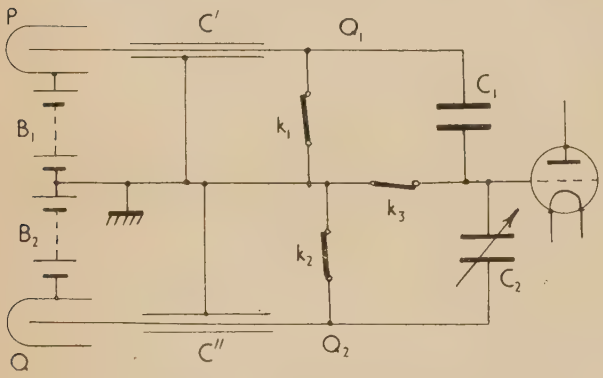


Fig. 2. Basic circuit of portable comparator

The appropriate balance condition then applicable has been shown in earlier papers$^{(1,4,7)}$ to be

$$\frac{Q_1}{Q_2} = \frac{C_1 + C'}{C_2 + C''} \cdot \frac{C_2}{C_1}$$

Clearly the reading on the scale of C_2 may be made to give a direct indication of the value of Q_1/Q_2, which is, in turn, equal to the ratio of the ionization currents obtaining in the two chambers.

A calibration curve of the reading of the scale of C_2 against relative values of Q_1/Q_2 may be obtained by the method of induced charges previously described.$^{(5)}$ Alternatively, for the highest accuracy, a method of point-by-point calibration may be adopted,$^{(6,7)}$ eliminating the necessity of reading the scale of C_2, and enabling the instrument readings to be made on a precision potentiometer to four-figure accuracy. However, for rapid measurements in routine radiological work where the highest possible accuracy is not required, it i advantageous to have a direct-reading instrument scale, and preferably a linear one, for accurate inscription and interpolation. Greening$^{(9)}$ has described how this may be achieved by the addition of a second variable condenser C_3 (Fig. 3)

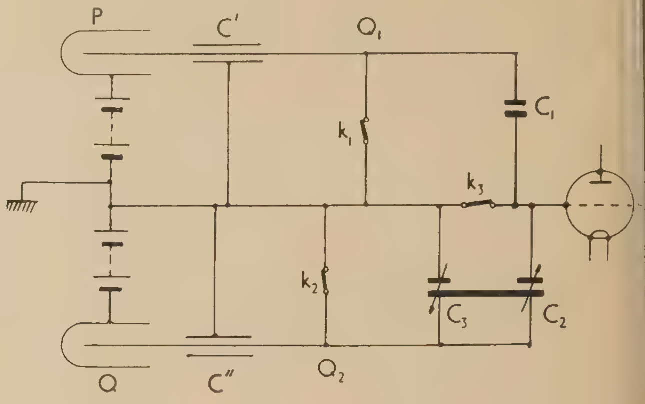


Fig. 3. Modified circuit to provide linearity of calibration

ganged to C_2, and so arranged that $(C_2 + C_3)$ remains constant. The balance condition then becomes

$$\frac{Q_1}{Q_2} = \frac{C_1 + C'}{(C_2 + C_3) + C''} \cdot \frac{C_2}{C_1}$$
$$= \text{constant} \times \frac{C_2}{C_1}$$

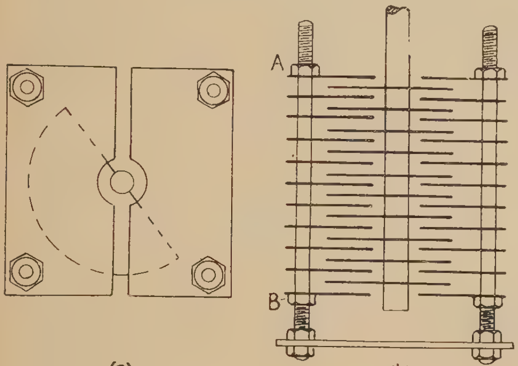
Thus, the Q_1/Q_2 ratios will be directly proportional to C_2, and if the latter has a linear law, the instrument scale itself will be linear. It is easily shown that, in practice, this arrangement has the further advantage of making the calibration, in effect, independent of the chamber cable capacities C' and C'', thus enabling different chambers to be plugged in without affecting the direct-reading qualities of the instrument.$^{(9)}$

Greening has further pointed out that if the (normally) fixed component C_1 of the capacity divider is made adjustable then the initial observation of a series may be made to correspond to "100" on the direct-reading scale by pre-setting the fixed capacity C_1 during the initial balance. The other readings of the series are then obtained (leaving C_1 fixed) direct from the dial of C_2 as percentages of the initial Q_1/Q_2 value.

CONSTRUCTIONAL FEATURES

Only new features, developed during the construction of the present portable instrument, will be described here. For general constructional details, reference should be made to the earlier papers.

The ganged condenser pair $(C_2 + C_3)$. This may comprise two linear-law condensers ganged in "anti-phase" by coupling their spindles. The accurate trimming of their capacities so that their sum remains sensibly constant throughout their rotation is not a particularly easy matter, however. A more elegant arrangement serving the same purpose is that of a so-called "differential" condenser, constructed from two sets of fixed vanes, sharing a single set of moving vanes [Fig. 4(*a*)]. In effect, all that is necessary is to add a second set of fixed vanes to the condenser comprising C_2: the moving vanes are connected to one of the chamber input sockets, ne set of fixed vanes to the electrometer valve grid, and the ther set of fixed vanes to earth (Fig. 3). The trimming of his double condenser so that the sum of the capacities of the wo sets of fixed vanes to the single set of moving vanes emains constant throughout rotation (apart from inevitable "end-effects") is a relatively easy matter, particularly as the se of a common set of moving vanes eliminates one possible ource of variation. The value of ($C_2 + C_3$) can be kept ell within ±1% limits. A useful point to bear in mind uring this trimming procedure is that the "local" capacity f fixed to moving vanes is always increased by any dislacement of the vanes which throws the moving vanes away rom the centre of the fixed vane spaces. Thus, shifting both he nuts *A* and *B* [Fig. 4(*b*)] upwards (or downwards) will ncrease the capacity of the moving vanes locally to this set f fixed vanes. A few very slight adjustments of this kind at ach of the four corners of the double condenser assembly asily achieves the desired result.



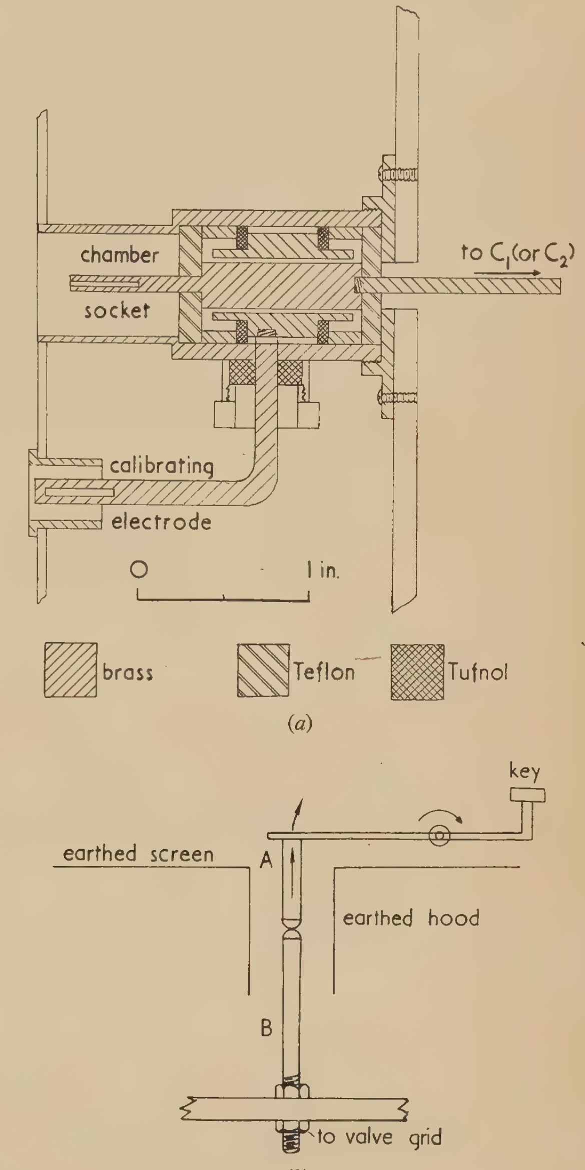
(a) (b)

Fig. 4(*a* and *b*). "Differential" form of condenser comprising ($C_2 + C_3$)

The pre-set condenser C_1. This comprises a single linear-aw condenser identical in form with those used in the contruction of the differential condenser described above, but aving a slightly higher maximum. The edge of the dial ttached to C_1 is fitted with a clamp to prevent accidental lteration of its setting after the initial balance has been chieved by means of this condenser.

The moving vanes of both C_1 and ($C_2 + C_3$) are driven hrough amber bushes, and the fixed vanes insulated by Teflon. In the present instrument, both condenser assemblies ave been surrounded by thin brass boxes covered by 2 mm f lead as some precaution against ionization arising between he condenser vanes from stray radiation.

The calibrating capacities. The principle and mode of use f these have been described in an earlier paper.(7) Hitherto hey have been devices which have been plugged into the nstrument as required. In the present comparator miniature ersions are used and they are made integral with the chamber nput sockets for convenience. A section of one of them is hown in Fig. 5(*a*). Essentially each comprises a cylindrical lectrode surrounding the rod which connects the centre pin f the chamber socket to the appropriate end of the capacity otential divider. It was found necessary to screen the central onductor from the insulating rings supporting the calibrating lectrode by carrying the latter well beyond the insulators Fig. 5(*a*)]; otherwise some creepage of charge across these nsulators could be "seen" by the central conductor, causing drift of potential on it. These built-in capacities enable known charge ratios to be induced on the comparator for calibration purposes. When not in use the calibrating electrodes must be kept earthed.



(*a*)

(*b*)

Fig. 5. (*a*) Section of chamber input plug and calibrating capacity. (*b*) Earthed hood minimizing capacity change due to earthing key movement

Screening. To achieve linearity of calibration, the two input circuits, together with the two halves of the capacity potential divider, must be completely screened from one another to prevent the appearance of a stray shunt capacity across the capacity potential divider. It has been shown(7) that even when this shunt capacity is as low as 1 pF it will affect significantly the shape of the calibration curve, particularly at the end of the instrument range (i.e. when C_2 assumes low values). In the practical lay-out, the electrometer valve and its batteries are accommodated in a central screening compartment, lying between the two input circuit compartments, whilst the galvanometer-lamp batteries and chamber-voltage batteries are accommodated in the back compartment containing the galvanometer system.

Earthing keys. These are so grouped that although each of the three lies in its own appropriate screening compartment, all may be operated separately with the fingers of the same hand by means of press buttons grouped close together on the instrument panel (Fig. 1). A single spring-loaded lever is also fitted which, through three cams, provides ganged operation of the keys when required. Milled edges on the cams project through slots in the instrument panel and enable the cams to be pre-set in "click" positions to give any desired operating sequence. Reference has already been made to the necessity to screen off from the rest of the circuit as much as possible of the moving parts of the earthing keys.(4) The use of a sub-miniature electrometer valve has made it necessary to take additional precautions in the case of the grid earthing key in order to avoid significant capacity changes as the key is operated (with consequent change in grid potential—seen as a small sudden change in the galvanometer deflexion when the key is opened). The contact rod *A* projecting through the earthed screen [Fig. 5(*b*)], movement of which is responsible for the undesirable capacity change, is surrounded by what might be termed a "Faraday cylinder" mounted on the earthed screen. The rod *B* serving as the grid contact projects well up into this cylinder, so that the actual contacts meet deep inside the latter. Changes in the capacity of the grid system to earth are thereby reduced to insignificance. This simple device greatly enhances the "handling" quality of the instrument.

Electrometer system. The valve used was a Mullard type ME 1402 in the circuit shown in Fig. 6. It was mounted in a spring-suspended Perspex ring to eliminate microphony. Noteworthy points regarding this circuit are the use of:

(*a*) Mallory mercury dry cells throughout (apart from the galvanometer lamp and chamber voltage supplies);

(*b*) a bridge circuit, which gives greater operating stability(4) and eliminates the necessity of backing-off the galvanometer. The valve is operated at a bias equivalent to the so-called "floating grid-potential" condition, the bias being adjusted so that no change in anode current occurs when the grid is disconnected from earth, the ionization chambers being, of course, disconnected;

(*c*) a continuously variable Ayrton–Mather type of galvanometer shunt as a sensitivity control;

(*d*) a two-stage "on-off" switch which ensures that the filament voltage is applied just before the anode voltage, as stipulated by the makers of the valve.

The galvanometer system. This uses a Tinsley type 4500 taut-suspension galvanometer movement (sensitivity 70 mm/μA at 50 cm), and the beam from the galvanometer mirror is reflected from two stationary mirrors before reaching the small ground-glass panel in the top of the instrument (Fig. 1). The galvanometer lamp switch is ganged with a switch which shorts the galvanometer movement when not in use, whilst the mechanical zero of the galvanometer is brough out to the instrument panel as a screw-driver control.

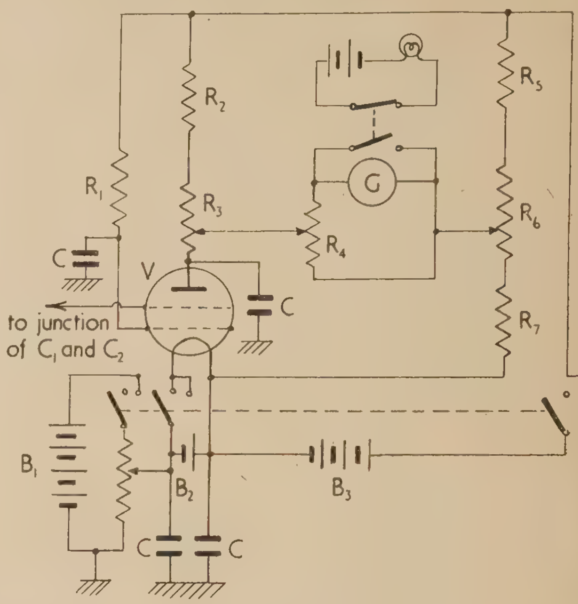


Fig. 6. Electrometer circuit

$R_1 = 15$ kΩ
$R_2 = 20$ kΩ
$R_3 = 100$ Ω(fine galvo. zero)
$R_4 = 2{\cdot}5$ kΩ (sensitivity control)
$R_5 = 1$ kΩ
$R_6 = 1$ kΩ (coarse zero)
$R_7 = 2{\cdot}5$ kΩ

$B_1 = 4$ Mallory cells

$B_2 = 4$ Mallory cells *in parallel*
$B_3 = 3$ Mallory cells
$C = 0{\cdot}05$ μF (tubular)
$V =$ Mullard ME 1402 electrometer tetrode
$G =$ Tinsley type 4500 taut-suspension movement (70 mm/μA a 50 cm.)

ACKNOWLEDGEMENTS

It is a great pleasure to acknowledge the skill and patience of Mr. Charles Ellis, exercised in the development and construction of this instrument.

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Laboratory and workshop notes

Curved spectroscopic slits

By D. A. Davies, B.Sc., Chemical Physics Section, Division of Industrial Chemistry, Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia

[*Note received* 28 *May*, 1956]

It has frequently been necessary to provide curved slit jaws for spectroscopic slits and two simple methods of doing this have been devised. Middleton* has described a method which is suitable only for brass or other soft materials.

The first is based on the principle that a plane section of a sphere is a circle. A spherical copper lap of the form shown in Fig. 1, that is, convex on the periphery and concave on the end face, is prepared with 20 μ diamond powder. The diamond powder mixed with oil is smeared over the spherical surfaces and pressed into the surfaces with a small ball race mounted on a handle, whilst the lap rotates in the lathe.

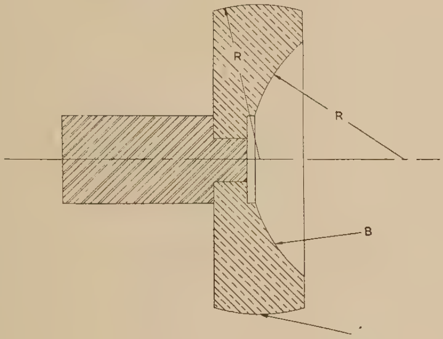

Fig. 1. Sectional elevation of copper lap

The slit jaw, made from hardened martensitic type stainless steel and suitably bevelled, is held in a small tilting vice and presented to the rotating lap which is kept lubricated with kerosene (Fig. 2). (The bevelling of the jaws is unimportant so long as it is at a more acute angle than the face generated by lapping, which is thus limited to a small area at the edge of the jaw.) Surface *A* is used for concave and surface *B* for convex jaws. If the base of the vice is flat and rests freely on a lubricated flat surface it is very easy to sweep the slit jaw across the full face of the lap and so ensure even wear. The radius generated is determined by the chord of the sphere containing the slit and this is easily altered by changing the tilt of the vice. This arrangement is most suitable for slits of small radius and one lap of radius *R* will generate slits of $0{\cdot}5R$ to $0{\cdot}77R$ approximately. The slits produced by this method are, of course, knife edges.

For slits of large radius where a lap as above would be too bulky, the author has used cylindrical glass laps cut from plate glass after the manner described by Twyman† for making gauges for lens tools. A piece of glass about 6 × 3 in. is scribed longitudinally with a glass cutter on a radius bar at the chosen radius. The glass is broken into two pieces which are then ground together on their curved edges whilst resting on a flat plate. Succeedingly finer grades of abrasive and frequent reversals of plates side for side and end for end, soon result in clean edges on the glass.

The suitably bevelled steel jaws are then worked against the glass laps with an appropriate fine abrasive to produce the required curvature. In this case the slit is in the form of a truncated knife edge. With care this flat can be kept below 50 μ particularly if the jaw be first prepared as a knife edge of approximately the correct curvature before being worked on the lap. This may very readily be done with a fine carborundum hand hone.

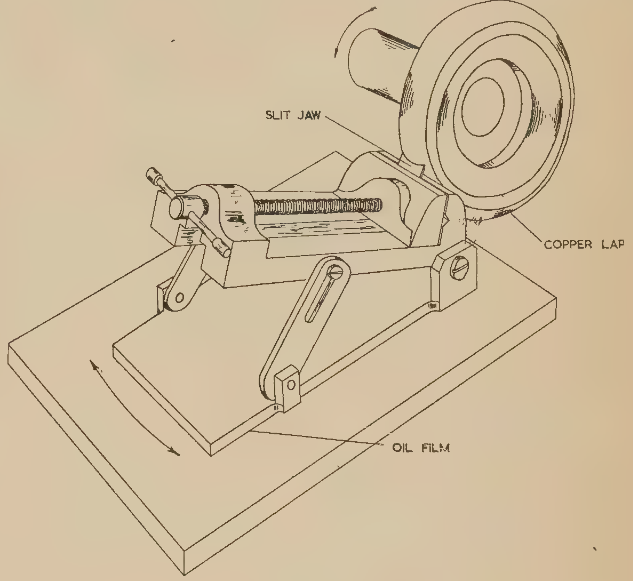

Fig. 2. Method of lapping slit jaws

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* Middleton, S. P. *J. Sci. Instrum.*, **32**, p. 399 (1955).

† Twyman, F. *Prism and Lensmaking* (London: Hilger and Watts Ltd., 1952).

Simple voltage change measurement

By B. J. Belcher, B.Sc., Imperial College of Science and Technology, London, S.W.7

[*Note received* 28 *June*, 1956]

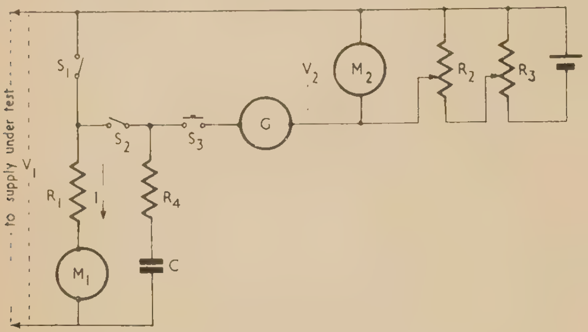
The following method was devised to measure a small change of the order of $0{\cdot}1\%$ in a supply of about 300 V, using apparatus readily available.

The principle of this system is that a large high insulation capacitor is used as a voltage reference while the supply is loaded. The supply is then unloaded and the voltage change backed off using a galvanometer as an intermittent null indicator.

Referring to the figure, the resistor R_1 loaded the supply *via* the switch S_1, and the current I through this resistor was measured by the meter M_1. The reservoir capacitor C was isolated from the supply by the switch S_2 (in this case a 4 μF polystyrene capacitor was used). It was found convenient to derive the backing-off voltage from potentiometers R_2 and R_3 fed from an accumulator (the two potentiometers allowing a finer adjustment than one). This voltage was measured on a moving coil meter M_2. The null indication was given by a sensitive reflexion type galvanometer, isolated by the push switch S_3 from the capacitor C. The resistor R_4 is merely a limiting resistor.

In operation, switches S_1 and S_2 are closed, thus charging C to the supply voltage on load, and the current I noted.

Switch S_2 is then opened, to isolate C, followed by switch S_1 to unload the supply. Potentiometers R_2 and R_3 are then adjusted so that the galvanometer gives no kick when S_3 is pressed, having just completed the sequence indicated above. The voltage V_2 is then clearly the supply voltage change for the load current I, and the effective resistance of the supply is simply $R_s = V_2/I$.



The use of a universal indicating instrument to measure low resistances

By J. C. Cooke, M.A., University of Malaya, Singapore

[*Note received* 12 *March*, 1956]

An instrument such as the Universal Avominor (by Automatic Coil Winder and Electrical Equipment Co. Ltd.) can be used to measure resistances of from 0 to 20 000 Ω with its own internal battery, the greatest percentage sensitivity being at 500 Ω. For higher resistances an outside source of voltage is required and the makers provide a short connecting link of wire with two plugs to facilitate this measurement.

The author has never seen mentioned the fact that the instrument can be used to measure quite accurately resistances of from 1 to 1200 Ω the greatest percentage sensitivity being at 24 Ω. The arrangements are simple and no outside source of voltage is required. In the method the unknown resistance is connected as a shunt to the instrument.

The socket marked 20 000 Ω is connected to that marked 500 mA by the connecting lead provided. This gives a reading near full scale which can be adjusted to full scale by the variable resistance knob provided.

The main testing leads are plugged, one into the common negative socket and one into the 2·5 mA socket. The unknown resistance is attached to the testing leads and the reading noted in the ohms scale. By dividing this reading into 12 000 one has the value of the unknown resistance in ohms. This is remarkably accurate for resistances above 1 Ω. For 1 Ω it is found that the reading is almost on the 10 000 Ω mark, and so is just a little out, but 2 Ω brings the reading almost exactly to 6000 Ω and any resistance higher than this is measured very closely indeed.

If the leads are shorted the needle goes very nearly to the zero of the scale, about half-way between this zero and the 20 000 Ω mark. The plugs, sockets and crocodile clips must be in a reasonable state of cleanliness for the method to succeed.

Note added in proof. Since this note was written the author had heard from the makers of the Universal Avominor that their latest model 1A includes this particular test and has an additional scale for it. The only difference is that the makers recommend that the short connecting lead is joined between the common negative and the 20 000 Ω sockets and the test leads go into the 500 and 2·5 mA sockets. This effectively produces the same circuit as given above.

Fabrication of holes of about 1 μ in diameter used for producing α-particle microbeams

By Marguerite I. Davis, Ph.D., and C. L. Smith, Ph.D., Department of Radiotherapeutics, University of Cambridge, and P. C. Smethurst, F.R.P.S., Smethurst High-Light Ltd., Bolton, Lancs.

[*Note received* 29 *May*, 1956]

During the course of the past two and a half years apparatus has been designed and constructed suitable for the irradiation of single parts of individual cells in tissue culture with fine beams of α-particles.* In order to produce α-particle beams 1 μ–1½ μ in diameter, collimating holes about 1 μ in diameter are needed. This problem has also been attacked by Zirkle and Bloom.†

The starting point for the collimator, which is to be used with the α-particles of energy 5·9 MeV emitted by a polonium 210 source, is a 3 mm diameter copper disk some 20 μ thick. These disks are normally used as the collimator and objective in electron microscopes, and are not normally available with aperture diameters much less than 12 μ, but since they are produced by electroforming in a copper-plating bath from a photo-produced matrix, it has proved possible, by judiciously increasing the thickness of copper deposited on the matrix, to reduce the diameter of the aperture to 6 μ without impairing its circular shape. Direct production of aperture diameters by this means, about 1 μ in diameter, is unfortunately not practicable, so that a second operation is required before the 6 μ holes, as produced by electro-forming, can be considered suitable for α-particle collimation.

To reduce the diameters of the holes to about 1 μ, metal is evaporated on to the copper disks in a vacuum. Several different metals have been tried, namely, gold, tin and aluminium. Tin has been finally found to be the most satisfactory. Gold does not adhere very well and after a few weeks begins to peel away from the copper surface. Furthermore, as α-particle scattering is proportional to Z^2, the number of α-particles scattered by a gold film is large; thus effectively broadening the beam. On the other hand (α, *p*) reactions become more probable with elements of low atomic number, e.g. aluminium, and the long range disintegration protons produced by bombardment of the metal with the intense α-particle source may be many more than the α-particles coming through the hole. For this reason the use of aluminium, though in every other respect an admirable metal, had to be abandoned. Finally, tin in the middle of the Periodic Table was chosen as the most suitable metal for deposition. Its atomic number is low enough for α-particle scattering not to be important and yet high enough for the (α, *p*) reaction not to occur with α-particles with the energy emitted by polonium. In addition it is very easy to deposit by evaporation in a vacuum and, perhaps because it does not easily oxidize, the resultant film adheres well and permanently to the copper disk. The film must be of sufficient thickness, approximately 5·5 μ, to stop the α-particles from polonium.

The evaporating apparatus, which is quite standard, is own in Fig. 1. Eight copper disks, placed in the small brass *X*, are treated simultaneously. They are placed at least cm from the evaporating filament *F* and are cleaned after ing placed in position, by passing a discharge at low essure through the gas in the bell jar using the brass jig d copper disks as one electrode. This is repeated at every vaporation. Only a small quantity of metal is evaporated ach time and sometimes as many as thirty evaporations are eeded to reduce the diameter from 6 to 1 μ. If the number f evaporations is reduced, either by bringing the jig closer o the filament or by using more metal for each evaporation, he hole appears to be filled with what seems to be a network f intercrossing strands of tin before the edges are built up. fter each evaporation the hole diameters are checked under microscope. It is not easy to measure diameters less than μ with an air objective and, of course, oil immersion bjectives cannot be used as the hole is then filled with oil. elow 1 μ the diameters of the diffraction rings increase apidly.

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* Davis, Marguerite and Smith, C. L. To be published.

† Zirkle, W. E., and Bloom, W. *Science*, **117**, p. 487 (1953).

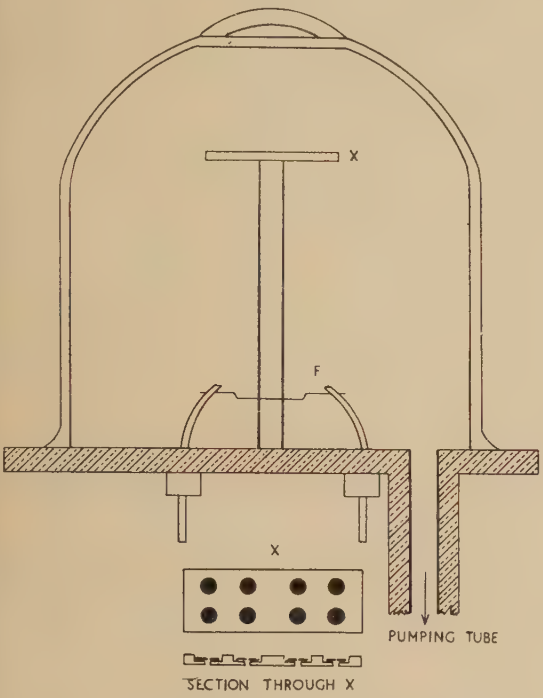


Fig. 1. Diagram of evaporating apparatus

From observations we have made on a 2 μ diameter hole nder a microscope using reflected illumination, it is quite bvious that these holes are originally conical in shape Fig. 2) and that evaporation probably serves to fill the cone ith tin metal. From the geometry it is clear that in order o fill such holes the tin atoms should be moving in a direction as nearly as possible perpendicular to the surface of the copper disk, i.e. the evaporating filament and disk must be separated by as large a distance as possible. If this distance is reduced too much, in order to increase the rate of deposition, shadows are produced and the deposition becomes uneven. A properly filled-in hole appears to have approximately the same diameter as that of the emerging α-particle beam. This shows that the hole must have sufficiently thick edges to stop the α-particles. Fig. 3 shows the photomicrograph of an α-particle beam emerging from a hole optically 1·5 μ in diameter taken perpendicularly to the direction of motion of the α-particles. These photographs were taken with a film of mica 5 μ thick between the hole and the nuclear emulsion. The nuclear emulsion which is 4 μ thick has been viewed from the surface away from the source. The geometry of the source is such that the beam of particles spreads with a half-angle of about 4° so that at a distance of 9 μ a beam initially 1·5 μ in diameter has become 2·9 μ in diameter. It can be seen from the photomicrographs that the α-particle beam is about 3 μ in diameter from which the aperture diameter can be calculated to be 1·5 μ in agreement with the observed optical diameter of 1·5 μ.

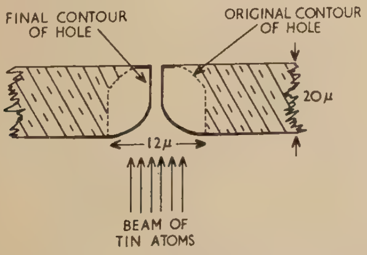


Fig. 2. Filling of holes by tin evaporation

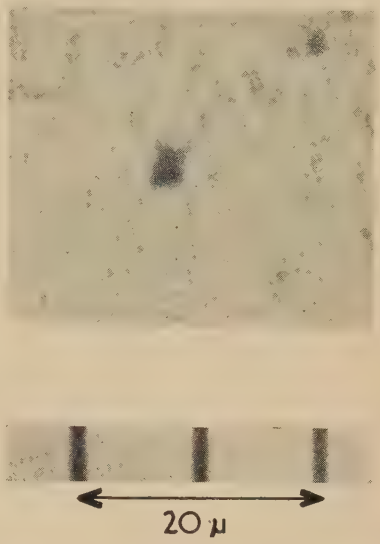


Fig. 3. Photomicrograph of α-particle beam

One of us (M. I. D.) is a U.S. Public Health Fellow of the National Cancer Institute.

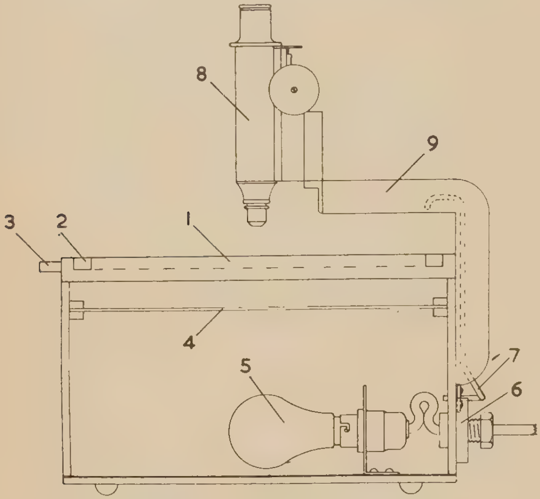
Wet viewing microscope

By R. C. Moss, Department of Physical Chemistry, University of Cambridge

[*Note received* 9 *July*, 1956]

Often it is necessary to examine photographic plates for fine detail as soon as possible after exposure and development. A hand lens is adequate for qualitative work, but for assessing, say, a series of focus photographs, something more precise is required. Recently Dr. J. S. Courtney-Pratt suggested that we should mount a microscope and illuminator suitable for viewing wet plates. The apparatus is shown in the figure.

The base is made as a box of Perspex. The sides and bottom are black and the top is a clear sheet $\frac{3}{4}$ in. thick. The top and sides of the box are screwed and glued together, while the bottom is screwed on with a rubber gasket between so as to be easily removable. Around the top plate, a small distance from the edge, is a groove $\frac{1}{2}$ in. wide and $\frac{3}{8}$ in. deep to collect any liquid that drains from the plate during use. The groove can be emptied through a hollow spigot at one side. Inside the box a sheet of flashed opal glass is mounted just below the top plate and below this is placed a 250 V, 25 W pearl bulb, the supply lead of which passes through a packed gland in the side of the base. A breathing tube has been fitted with its outlet taken well above the working surface and protected by the overhang of the support bracket. Where it passes into the box it is sealed with a rubber gasket. All screws passing through the Perspex are sealed after insertion, which means that the whole box is watertight and may be immersed in water to wash off any chemicals.



Sectional elevation of microscope and illuminator

(1) $\frac{3}{4}$ in. Perspex work surface; (2) drain trough; (3) outlet for trough; (4) flashed opal glass; (5) 25 W bulb; (6) watertight gland for lead; (7) breathing tube; (8) microscope tube; (9) support arm.

A simple focusing microscope tube (No. 2308, made by R. and J. Beck Ltd.) is mounted on a stiff bracket that also forms a convenient carrying handle. Any ordinary objectives and eyepieces can be used. We have fitted a ×5 objective and either a ×4 or ×10 eyepiece.

An optical apparatus to measure shrinkage at high temperature

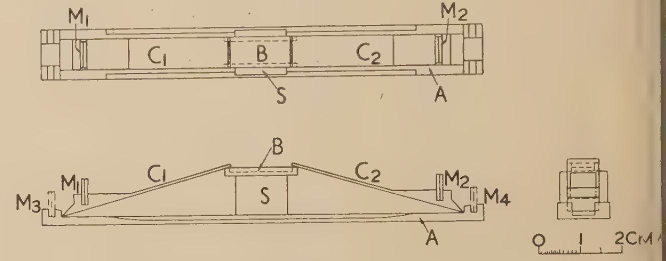
By J. Hutchings and J. P. Roberts, M.A., B.Sc., Royal Aircraft Establishment, Farnborough, Hants

[*Note received* 17 *August*, 1956]

The apparatus illustrated in the figure was developed for continuous measurement of the shrinkage occurring during sintering of powder pressings. The compactness, simplicity of design and construction in ceramic material have allowed us to use the apparatus inside small furnaces up to 1300° C. Operation at higher temperatures appears to be feasible.

Components A, B, C_1 and C_2 are made of sintered alumina, cut by diamond equipment. The rectangular specimen S rests on component A with contact along rails of a width (1 mm) which provides sufficient support to prevent distortion of the specimen during sintering but which also gives the sintering atmosphere considerable access to the specimen. Component B rests on S, again with rail contact. Components C_1 and C_2 rest on A and B, and carry respectively high-temperature mirrors M_1 and M_2, which are set in position with alumina cement (not shown). When S shrinks C_1 and C_2 pivot about their knife-edge contacts with A. The linear shrinkage at any instant is easily calculable from the mean deflexion of beams of light directed on to each of the mirrors M_1 and M_2. The optional fixed mirrors M_3 and M_4 provide reference reflexions, advisable if there is risk of relative movement between the apparatus and external scales.

Fused silica sputtered with platinum has proved to be satisfactory for mirrors up to 900° C. Unmetallized corundum crystal ("sapphire") may be used up to at least 1300° C, bu the lower reflectivity of this material necessitates strong ligh sources such as arc lamps.



High-temperature apparatus for shrinkage measurement

The magnification of the change of thickness of the specimen is seventy times when the reflected light falls on scales at 1·5 m from the mirrors. The specimen is normally 1 cm high and shrinkages up to 1 mm are measured. The shrinkage at any time can be determined to within 10 μ (refraction and expansion effects causing an uncertainty of this order), whilst the apparatus is sensitive to movements down to 5 μ.

Acknowledgement is made to the Controller, H.M. Stationery Office, for permission to publish this note.

Spring diaphragms

By D. F. Gibbs, B.Sc., A.Inst.P., H. H. Wills Physics Laboratory, University of Bristol

[*Note received* 3 *July*, 1956]

In physical apparatus it is frequently convenient to use a flat diaphragm spring of phosphor-bronze or similar material to constrain some part to move linearly in one direction. An example of its use is in the Sucksmith balance.(1) In such cases a diaphragm with a spiral cut is often used as shown in Fig. 1, the diaphragm being clamped round the edge and the moving part being connected to the centre. This arrangement is stiff to displacements in its plane, and two such diaphragms mounted one above the other with their centres connected by a rod will constrain the rod to move approximately along its own axis. It is capable of fairly large displacements but suffers from the defects that the motion is not very accurately rectilinear, the rod tends to rotate about its axis as it is displaced, and may also experience a torque about an axis in the plane of the diaphragm. A multiple start spiral is an improvement.

A more symmetrical method of perforation which avoids these defects is shown in Fig. 2, the principle being reminiscent of that used in some types of paper chains for decoration. This type of diaphragm tends to be much stiffer, however, than that shown in Fig. 1 and moreover the stiffness is nonlinear, the force increasing rapidly as the centre is displaced, owing to second-order components of strain in the plane of e diaphragm, so that in practice it may be suitable only r rather small displacements.

A form which is symmetrical and allows of considerable splacements is shown in Fig. 3. The second order dis-acements in the plane of the diaphragm are approximately mpensated by a principle described by R. V. Jones(2,3) and bstantially anticipated by R. S. Clay.(4) Variations which ave been used to permit the motion of a central rod relative o three rods equally spaced round it, and to permit the otion of three rods relative to three others spaced uniformly etween them on a circle, are shown in Figs. 4 and 5 espectively. In the latter two cases the edge is free. The iaphragms were made of beryllium copper by coating with ax, drawing the design with a needle and etching with itric acid. If the thickness is greater than a few thousandths f an inch, it is advisable to etch from both sides. For heat reatment the diaphragms were clamped between thick brass lates; this helps to reduce the tendency to buckling which ay cause regions of negative stiffness, resulting in a snap ction.

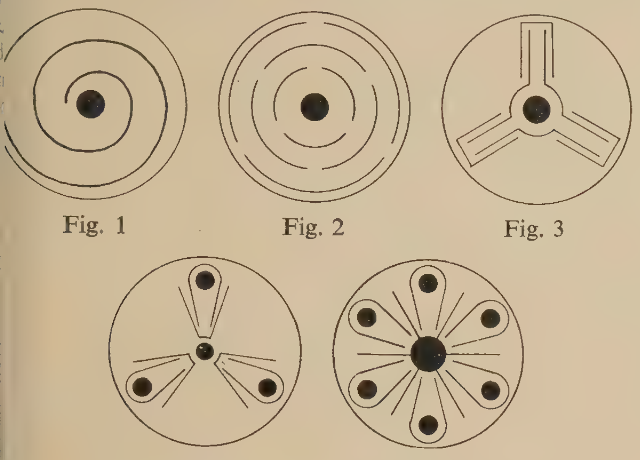


Fig. 1 Fig. 2 Fig. 3

Fig. 4 Fig. 5

Figs. 1–5. Types of spring diaphragms

For the successful construction and employment of these iaphragms thanks are due to Dr. H. Allsopp, Mr. M. Madden and Mr. G. Grainger.

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as-cooling device for use with a 19 cm X-ray powder camera*

By M. H. Francombe, M.Sc., A.Inst.P., Research Laboratories of The General Electric Co. Ltd., Wembley

[*Note received* 5 *June*, 1956]

everal attempts have been made in recent years to modify 9 cm diameter powder diffraction cameras for use at low emperatures. Amongst the simplest methods described in he literature may be mentioned those developed by Tombs(1) sing liquid cooling at fixed temperatures, and by Thewlis nd Davey(2) who employed gas cooling. Disadvantages of he gas-cooling techniques so far used are:

(*a*) the vaporized coolant is permitted to come into contact with the film, and;

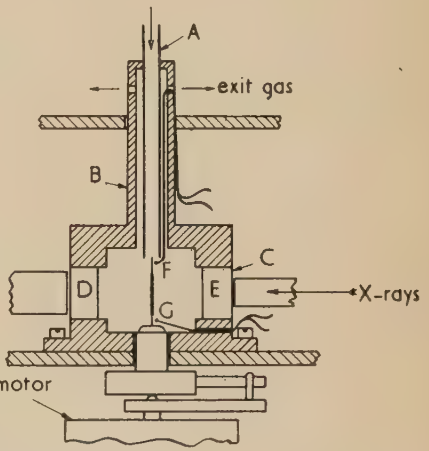
(*b*) the consumption of coolant is rather excessive.

The first effect becomes especially objectionable when accurate measurements of lattice parameters are required, since during the exposure changes in the length of the film may be caused by shrinkage.

We have designed a simple and robust gas cooling device which fits into a standard 19 cm Unicam camera in such a way that the gas coolant enters and leaves without touching the film. Thus both the film and the camera body remain substantially at room temperature throughout the exposure. Moreover an autogenous cooling effect is produced which considerably reduces the consumption of the coolant.

The figure shows a sectional view of the cooling chamber positioned in a camera which may also be used for the liquid-cooling method. The gas coolant is obtained in the usual way by boiling liquid air with an immersion heater in a Dewar flask having an aperture at the bottom. The aperture is fitted down over the brass tube *A* and the cold vapour enters the tube after first passing through the liquid air in the flask in the manner described by Vonnegut and Warren.(3) After cooling the specimen the gas passes up through the annular space between the tube *A* and the cylinder *B* (made of Tufnol, a resin-bonded-paper laminate), and leaves through vent-holes above the camera lid. The upper and lower Tufnol parts of the cooling chamber are connected by two pairs of brass shields at *E* and *D*, which are placed in line with the ends of the collimator and beam trap respectively. The specimen space is completely enclosed by means of a window *C* made of X-ray film base. Scattered X-radiation arising from the window or from frost forming on it during use is prevented from reaching the film by the brass shields. The specimen temperature is taken as the mean of two readings obtained with copper-constantan thermocouples (made from 36 s.w.g. wire) at *F* and *G*.

Section of cooling chamber for use with a 19 cm X-ray powder camera



Temperatures down to −140° C are easily reached with small rates of gas flow and with a liquid–air consumption of about 1¼ l./h. For lower temperatures the rate of flow and coolant consumption need to be increased appreciably.

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* G.E.C. Communication No. 688.

Correspondence

The eccentric loading of optical flats during grinding

Mr. N. J. Rumsey* gives an interesting explanation of the fact that a glass block does not grind over the whole of its surface if the load is applied too far from the geometrical centre. However, his numerical conclusions depend upon equation (1) which assumes that the pressure has a linear distribution.

This is not necessarily true. What appears certain is that if an originally flat surface is to remain flat during grinding, the rate of removal of glass must vary linearly across the surface of the block. The pressure will distribute itself so that this is the case.

Suppose that a rectangular slab of glass is to be ground so that no glass is removed along one edge. Then measuring x from this edge the rate g of removal of glass must vary linearly across the slab, as

$$g = ax \tag{1}$$

The rate of grinding will depend in some way upon the pressure p. For the sake of discussion one may assume a power law

$$p = kg^n \tag{2}$$

The load must be applied at the centre of pressure. This is on the centre line of the slab at a distance A from the edge, where

$$A = \int_0^L pxdx \div \int_0^L pdx$$

$$= \frac{n+1}{n+2} \cdot L \text{ from equations (1) and (2)} \tag{3}$$

Mr. Rumsey assumes that n is unity and finds that A is $2/3\,L$, that is, the load should be applied $2\,L/3$ from one end. If n were $\frac{1}{2}$ the load would need to be applied nearer to the centre

$$A = \frac{3}{5} L \text{ for } n = \tfrac{1}{2}$$

or if n were 2 the load would need to be applied further from the centre

$$A = \frac{3}{4} L \text{ for } n = 2$$

Thus the allowable eccentricity in the loading, if double surfaces are to be avoided, depends on the law relating the rate of removal of glass to the applied pressure.

The fact that Mr. Rumsey's experiments agreed with his predictions seems to me a proof that the rate of removal of glass is proportional to the pressure applied.

306 Muritai Road,
Eastbourne,
Wellington,
New Zealand.

N. F. Barber
[21 August, 1956]

The fact that grinding rate is directly proportional to pressure was introduced in my paper as though it were merely a plausible assumption. However, this has been demonstrated by experiment, at least for optical glass.† Thus my deductions are valid for the materials with which I am concerned.

The interesting point arising from Barber's remarks is tha if there had been a non-linear relationship between grindin rate and pressure the whole of my analysis would have been invalid, even my equation (1). For though this equation may still be satisfied before grinding starts, it would no longer apply after some material had been removed. The non-linear pressure distribution necessary to ensure a linea grinding rate distribution in this case would, presumably arise through a very slight departure from flatness of the surface being worked.

Another possible source of an abnormal pressure distribution is a non-linear relationship between stress and strain In this case the distribution would fail to satisfy my equation (1) before grinding starts.

In my paper a simple experiment was described where three-quarters of the length of a rectangular slab of glass was found to be ground when the total load had been applied at one-quarter of the length from one end. It follows from Barber's analysis that if the material being worked is abnormal in its relationship, either between grinding rate and pressure, or between stress and strain, this experiment would give a different result. The experiment could therefore provide a very simple test for abnormality, though it fails to distinguish in which respect the material is abnormal.

Dominion Physical Laboratory,
Lower Hutt,
New Zealand.

N. J. Rumsey
[28 August, 1956]

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* Rumsey, N. J. *J. Sci. Instrum.*, **32**, pp. 338–339 (1955).

† French, J. W. *Dictionary of Applied Physics*, Vol. 4, pp. 326–348 (London: MacMillan and Co. Ltd., 1923). (See Fig. 18, p. 337.)

Vacuum deposition apparatus

Holland* describes a window wiper for vacuum coating apparatus which facilitates removal of condensed metal films from a window used for viewing the vapour source, but points out that the wiper could not be incorporated in optical coating plant owing to the appreciable vapour pressure of the oil used on the wiper blade. A device free from this restriction, and used in the present writer's various laboratories over the last ten years, comprises two slips of glass exposed to the vapour beam in the vacuum chamber, one serving to keep the observation window free from metal by simple obstruction of the beam and the other acting as a mirror in which the vapour source and other contents of the chamber can be viewed through the window. Alternatively, the glass slips can both serve as mirrors when arranged in the form of a simple periscope. Many other arrangements are possible, including multiple mirror systems to eliminate the displacement of line of sight associated with periscopes and spherical surfaces to form wide angle mirror systems. In all cases, continued evaporation merely serves to refresh the metallized surfaces of those slips acting as front surface mirrors and does nothing to impair the obstructive properties of those shielding the observation window, so that there is never any interruption of view.

National Coal Board,
Mining Research Establishment,
Isleworth, Middlesex.

F. W. Cuckow
[25 September, 1956]

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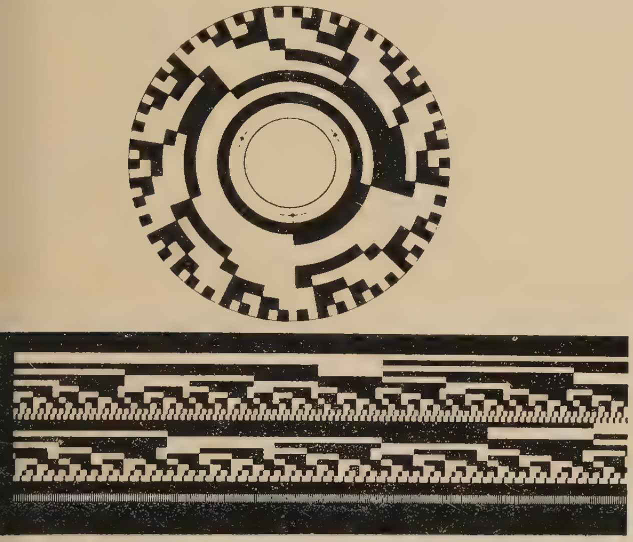
* Holland, L. *Vacuum Deposition of Thin Films*, p. 385 (London: Chapman and Hall Ltd., 1956).

New instruments, materials and tools

he Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved roducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

inary coded scales. Hilger and Watts Ltd. (Watts Division), 48 Addington Square, London, S.E.5.

inary scales are produced by this firm in various forms and ith various code arrangements to satisfy particular requirements. The scales are made on metal or glass and may be btained in circular or linear form, as shown in the figure. ick-off from the metal scales is by specially designed ontact arrangement and the glass scales are read by eans of Schwarz photoconductive cells which have been eveloped for these scales. The cells require a 10 V supply nd have output characteristics similar to photomultipliers. he sensitive areas are 1 × 0·2 mm and can be produced in ny group arrangement on a common base, the minimum pacing being 1 mm. Scanning systems for serial pick-off, sing a single photocell may be used. The scan may be enerated mechanically or electrically depending on the feed equirements.



Circular and linear binary scales

The minimum division of the metal scales is 0·015 in. with minimum track width of 0·062 in. to allow for brushes hilst the smallest division for the glass scales is 0·001 in. nd a minimum track width of 0·020 in. with a pitch spacing f 0·040 in. to allow for Schwarz photocells. The scales re in three types, the pure binary code, the binary-coded ecimal for use when direct conversion to decimal is required nd an arrangement, the cyclic-progressive binary ensuring at not more than one digit change occurs at any one time hilst moving over the scale.

acuum thermojunctions. Best Products Ltd., Felix Works, Felixstowe, Suffolk.

range of vacuum thermojunctions is available with heaters ated at 1·25 mA, 1600 Ω for the most sensitive to 1 A, ·15 Ω for the least sensitive type. The thermocouple output for maximum heater input is 7 mV in all cases. The ouple is electrically insulated from the heater and tested to 00 V d.c.

Special papers. Riegal Paper Corporation, 260 Madison Avenue, New York 16, U.S.A.

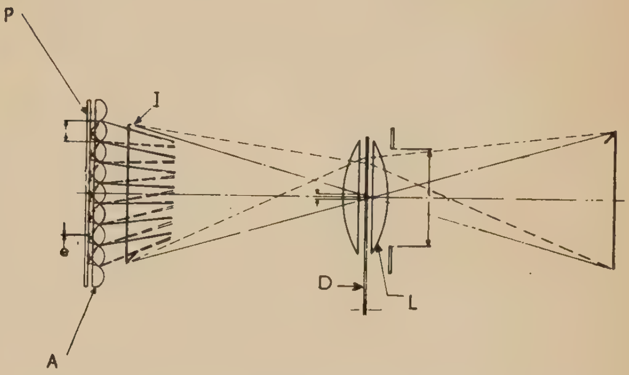
A range of papers having unusual properties includes nylon fibre paper and paper resistant to the passage of liquids. At present, both are prepared specially to meet the needs of each prospective users.

The nylon paper can be manufactured with widely different porosities and weights. The process "R-196" can be applied to many types of paper to render them resistant to the passage of liquids without affecting their natural air porosities.

High-speed camera. J. Langham Thompson Ltd., Bushey Heath, Herts.

The series 600 Courtney-Pratt high-speed camera has been developed from the original work of Dr. J. S. Courtney-Pratt.* It can record a series of 300 photographs at rates from 100 to 150 000 pictures per second.

An assembly of small lenses *A*, which are embossed in plastic and bonded to a glass plate, dissects the picture into a large number of small elements. Each set of picture elements is recorded simultaneously on a photographic plate *P* with a spacing between adjacent elements that is large compared with the size of each element. The displacement of the picture element is produced by altering the direction in which light falls upon the assembly of small lenses, this being achieved by using a Nipkow disk *D*, which is rotated between the elements of a normal photographic objective *L*. After processing, the photographic plate can be replaced in the film carrier in order to examine the high-speed phenomena at slow speed, or to take individual pictures of interesting characteristics. With the photographic plate replaced in the holder, a bright light source is introduced into the main camera lens which produces silhouette pictures on a ground-glass screen situated at the rear of the film carrier. This process may be reversed when convenient and the event displayed on a screen situated in the position that the object occupied whilst being photographed.



Construction of camera in diagrammatic form. A real image is formed in the plane *I* as in normal photography and, for a stationary object, the image is stationary for all positions of the aperture in the Nipkow disk *D*

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* Courtney-Pratt, J. S. *J. Photog. Science*, **1**, p. 21 (1953).

The rotation of the Nipkow disk will show on the ground-glass screen the series of photographs that was recorded at high speed. The aperture disk may be stopped in any desired angular position and simple contact prints taken of the event in its various stages of development. Each picture is dissected into 80 000 elements and these give an equivalent resolution of 250 lines across the film plate in one direction and 350 in the other. The photographic plate, which may be of any normal type, is 5 × 4 in. The magnification ratios range from 1 : 1 to infinity in eight settings. The recording rate is controlled by varying the speed of the Nipkow disk across the lens face. The speed is controlled by varying the voltage to the a.c. series motor which drives the Nipkow disk.

Each revolution of the Nipkow disk gives a complete series of pictures and double exposures will result if the photographic plate is exposed to more than one revolution of the disk. In some cases, such as objects which are self-luminous, there is no need to stop the exposure since the phenomena will terminate it, but for daylight photography and for cases where special transient illumination cannot be arranged, it is convenient to fit a shutter which will remain open for one revolution of the aperture disk. This item may be fitted to the camera as an optional extra and has a speed range which is variable to suit the speeds of the aperture disk.

The Dallmyer Pentac, 8 in. focal length, $f/2 \cdot 9$ aperture lens is arranged in such a manner that the Nipkow disk revolves between its main components. All the light that falls on any of the small lenses of the lenticular plate is concentrated into a picture element which is of much smaller area. The photographic brightness of any small point element is high. The effective numerical aperture of the lenticular plate camera is approximately a function of the pitch and focal length of the small lenses on the lenticular plate, and with the lenticular plates used the overall effective aperture is $f/6 \cdot 3$.

For convenience the Nipkow disk has been engraved so that angular positions may be easily set in order to process prints at intervals of time, in relation to the speed at which the photographs were taken. An indicator is situated at the front of the camera through which can be seen the divisions on the Nipkow disk, and by means of a manual control the aperture disk can be set to any desired position.

No standard arrangement of lighting has been recommended for use with the camera. Each specialized application has certain requirements, and these can be met more conveniently when the complete operating conditions are known. Advice can be obtained readily from the manufacturers.

Ionization electromechanical transducer. Decker Aviation Corporation, 1361 Frankford Avenue, Philadelphia, U.S.A.

A range of instruments has been developed based on the ionization transducer described by Lion.[*] This device consists of a small glass envelope filled with inert gases under reduced pressure and fitted with two internal probe electrodes. When placed between a pair of external electrodes connected to a radio-frequency source of approximately 5 Mc/s, a d.c. potential is produced between the probe electrodes. This is zero when the tube is symmetrically placed between the external electrodes and increases for displacements from this position. The sensitivity of the device can reach several kilovolts per millimetre displacement. A more generally useful arrangement is to excite the transducer by two external electrodes connected to the radio-frequency source and to connect the internal electrodes through a differential condenser to one of the external electrodes. Variations of the differential condenser produce corresponding changes in the d.c. voltage between the external electrodes. A sensitivity o 5 V/pF is obtainable for the detection of capacity changes This latter device is employed in the model 103 comparato micrometer, which gives full-scale deflexion for a change o linear dimensions of 20 μ in. Since the device depends on capacity variation, it does not require, in the case of meta specimens, an actual contact between the work piece and the micrometer head. Another instrument based on the same principle is a differential pressure gauge which uses a flexible diaphragm to convert pressure changes to capacity changes

Microprojector. Newbold and Bulford Ltd., Enbeeco House, Roger Street, Gray's Inn Road, London, W.C.1.

The Enbeeco microprojector consists of a metal case containing a transformer which will operate from a.c. mains supply of 200–250 V, together with a focusing mechanism and a surface-aluminized mirror and mounting. Illumination is provided by a 12 V, 100 W twin pillar, vertical, central filament projection lamp. The projection lens is a 1½ in. achromatic microscope objective in a standard R.M.S. mount. When not in use the mirror is housed in the lid of the casing and the two telescopic pillars slide down into the body of the projector. When the image from the objective is projected by the mirror onto the screen it is enlarged by approximately 50 diameters at a distance of 6 ft. Additional achromatic objectives may be added to the basic equipment.

Silver coating for glass and ceramics. Johnson Matthey and Co. Ltd., 73 Hatton Garden, London, E.C.1.

Silver pastes are available for depositing a thick silver film on glass or ceramic bases. The film is compact, electrically conducting, firmly adherent and can be readily soft soldered. When circular bands are applied to tubes or cylinders, the parts can be revolved mechanically against a stationary brush. The process involves the application of two pastes. The silver paste X351, which is applied first, contains a bonding agent which fuses into the glass or ceramic surface during firing and provides a secure bond. Owing to the presence of this bonding agent, it is difficult to solder satisfactorily on to X351 and a covering coat of X353, which consists of a suspension of finely divided pure silver, is necessary to provide a solderable film. After application of the pastes, the parts are fired at a temperature between 550 and 700° C.

Sleeves to replace grease in ground glass joints. Loughborough Glass Co. Ltd., Loughborough.

Polytetrafluorethylene sleeves for interchangeable ground glass joints are designed to stop sticking, and may be used instead of greasing the joints. The sleeves are truncated cones of polytetrafluorethylene film (about 0·003 in. thick), which has a waxy surface. The taper is accurately 1 in 10 so that the sleeves fit snugly on to their appropriate ground glass cones. Sizes are available to fit all joints within the range B7–B55 inclusive (BS. 572). The makers state that the sleeves are attacked only by molten alkali metals and fluorine and that there are no known solvents. Fitted to ground joints of good quality, the sleeves will hold vacua of the order encountered in vacuum distillation processes without using grease, and they will withstand temperatures in the range −75 to 250° C. They can be cleaned readily and used again and again.

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[*] Lion, K. S. *Rev. Sci. Instrum.*, **27**, p. 222 (1956).

New books

lectronic measurements and measuring instruments. By F. G. Spreadbury. (London: Constable and Co. Ltd., 1956.) Pp. ix + 459. Price 50*s*.

he large variety of electronic instruments and their multirious applications require of an author an unusually wide nowledge and experience if a textbook on this subject is to e authoritative and up to date. The present book cannot e considered entirely satisfactory in these respects and, lthough the author has made a serious attempt to tackle he problem, it would seem that he has aimed at covering oo wide a field. The book includes a large number of tandard electronic circuits and contains much information hat would be useful to a novice in the subject, for whom the ook is intended primarily. Unfortunately there is matter hat is dubious or incorrect, and, although this forms only a mall fraction of the whole book, there is nothing to guide a ro in the parts he should omit.

Some of the circuits are out of date and in a few the valves re not of the appropriate types; for example, in a voltmeter robe (Fig. 2.15) a high-voltage rectifier diode is shown nstead of a low-voltage type. A circuit is erroneously escribed as a "typical differential-voltmeter" (Fig. 2.24); it s not differential in the commonly accepted sense, and is nusual rather than typical. The voltage to be measured is pplied through a transformer to the filament of a saturated iode and the change in saturation current with filament oltage is used to measure the latter; the anode supply is also btained from the transformer. The writing is in places slapash to the extent of being incorrect; to quote an example, in eferring to skin-effect (p. 38) it is wrongly stated that "The atio of a.c. to d.c. resistance of a straight wire is proportional o $d\sqrt{(f/\rho)}$ . . ." and in the accompanying table no units re stated, nor are the values correct. A bibliography is iven at the end of each chapter, but the selection of the eferences is not as judicious as could be desired.

G. H. Rayner

Research report of the Royal College of Science 1953–1956. (London: Imperial College of Science and Technology, 1956.) Pp. iv + 64. Gratis.

This is the second of the triennial reports on the research work in progress in the Departments of the Royal College of Science, which is one of the three constituent colleges of the Imperial College of Science and Technology in London. It gives a brief report of the very wide range of research carried on in the Departments of Botany, Chemistry, Geology, Mathematics, Meteorology, Physics (including Technical Optics and Instrument Technology) and Zoology and Applied Entomology. In the Physics Department work is reported on rock magnetism, high energy and cosmic-ray physics, nuclear physics, spectroscopy, acoustics, electron physics, electron diffraction and microwave spectroscopy. The Technical Optics section has been concerned with the study of optical images, transmission of optical images, particle counting and sizing, colour measurement applied to natural phenomena and aspherizing of optical surfaces. There is a brief account of the establishment of the new Instrument Technology section, which is part of the expansion programme. The object of this group is research into, and development of, new techniques and instruments which appear likely to be of value in scientific research. So far the work has been mainly concerned with applications of what is generally known as "electronics" to a wide range of problems. In the Department of Mathematics work is reported on the following: theory of the physical properties of solids, theoretical nuclear physics, relativity and problems of cosmology and statistics. The Department of Meteorology has been working on a number of problems including physical climatology, numerical weather prediction, transfer processes, airflow over mountains, convection, cloud microphysics, macrophysics of clouds, radiation and exploration of the upper atmosphere.

H. R. Lang

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

Conical ground glass. Quickfit and Quartz Ltd., Heart of Stone, Staffordshire. A new 20-page catalogue, dealing exclusively with conical ground glass joints and giving full details of cones, adapter pieces and sockets, is intended particularly for those who have to make or repair laboratory glass aparatus.

All-metal ultra-high vacuum valve. Granville Phillips Co., Box 191, Pullman, Washington, U.S.A. A circular notice gives details of the firm's type C all-metal vacuum valve, which is stated to work down to 5×10^{-10} mm of mercury with a conductance from 1 to 10^{-14} l./s.

Piezoelectric ceramics. Technical Ceramics Ltd., Wood Burcote Way, Towcester, Northants. A 16-page illustrated brochure explains how barium titanate transducers and piezoelectric ceramics are manufactured and shows how they can be used in a wide range of applications.

Ultrasonic transducers. Technical Ceramics Ltd., Wood Burcote Way, Towcester, Northants. A new range of transducers for use in ultrasonics is announced in a leaflet. The ceramic is principally barium titanate in a polycrystalline form.

Refinery process refractometer. Consolidated Electrodynamics Corporation, 300 North Sierra Madre Villa, Pasadena, California, U.S.A. A press release announces a new process refractometer designed to monitor continuously the refractive index of liquid process streams in refineries and chemical plants.

Permanent magnets. James Neill and Co. (Sheffield) Ltd., Napier Street, Sheffield 11. Leaflet P.M. 162/56 gives particulars of a range of permanent magnets and illustrations of many ingenious applications.

Nine inch wet belt grinder. Taylor Tools and Supplies Ltd., Vortex Works, Broadheath, Altrincham. A press release announces a new 9 in. wet belt grinder employing electrocoated, resin-bonded abrasive belts.

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

Fellows: A. H. Anstis, W. D. Bennett, C. E. Challice, A. J. Dyer, G. M. Leak, J. G. Powles, J. R. Stansfield, E. J. W. Whittaker.

Associates: S. A. Ahern, J. R. Bell, A. G. Buswell, K. R. Canfor, F. P. Chappel, A. E. Chester, P. N. Cooper, K. K. Damodaran, J. R. Denholm, E. W. Dickson, G. Duckworth, J. E. Dyson, R. J. Edwards, K. Ellis, P. Fisher, J. J. Gameson, A. M. Godridge, M. J. Goodspeed, D. W. Green, F. Heath, S. Hill, J. N. Hodgson, H. L. W. Jackson, W. L. Jackson, T. O. Jeffries, I. M. L. Jenkins, J. M. Johnston, P. Kalman, R. J. Lamden, I. K. B. Legge, D. Lewis, J. R. H. Lewis, F. M. Lovell, H. A. McCloskey, L. Micco, A. J. Miller, B. A. M. Moon, A. C. T. North, P. H. Oliver, A. E. S. Pengelly, M. Possener, G. Power, R. G. Pratt, M. J. Puttock, C. A. K. Salgado, H. M. Scott, R. E. Shannon, R. H. Slater, R. W. Smith, G. Spurr, P. Swinbank, A. Tarnowski, H. W. Thomas, S. M. A. Tirmizi, G. J. Williams, G. W. Wilson.

Fifty-one Graduates, fifty-seven Students and five Subscribers were also elected.

The Physics of Nuclear Reactors

The proceedings of a conference arranged by The Institute of Physics in collaboration with the British Nuclear Energy Conference and held in London from 3 to 6 July, 1956, have now been published as Supplement No. 5 to the *British Journal of Applied Physics.*

The purpose of the conference was to keep members of the Institute and its sister Institutions abreast of scientific developments in nuclear reactors and to call their attention to the problems needing solution. The conference was particularly intended for industrial and government physicists, working or likely to work directly or indirectly with reactors, and for lecturers and other teachers.

The supplement contains thirteen papers, with discussions on them, and opens with a survey by Sir John Cockcroft of the scientific problems in the development of nuclear power. The aspects of the subjects which were discussed appear under the following headings: The physics of advanced reactors; Experimental reactor physics; The control of reactors; The role of chemistry in a nuclear energy project; The United Kingdom research reactors and their uses.

Additional copies of this supplement, bound in stiff covers, may be obtained from the publishers: The Institute of Physics, 47 Belgrave Square, London, S.W.1, price 25*s.* (including postage).

Three hundred years of pendulum clocks

On 4 December, 1956, the Netherlands Ambassador opened an exhibition at the Science Museum, London, commemorating the three-hundredth anniversary of the invention of the pendulum clock by Christiaan Huygens The exhibition has been organized by the Science Museum and the Antiquarian Horological Society, and exhibits have been lent by the Rijksmuseum voor de Geschiedenis der Natuurwetenschappen at Leiden and the Hessisches Landesmuseum at Kassel as well as by private collectors.

The exhibits illustrate Huygens' invention and trace the history of clockwork from the time of the "foliot" balance through the "cross-beat" to the earliest types of pendulum clocks, and thence through the long-case clock to the "regulator" or precision pendulum clock.

The exhibition will be open to the public until 24 February. An illustrated catalogue is available at the Science Museum, price 2*s.* 0*d.* Hours of opening: Weekdays, 10 a.m. to 6 p.m.; Sundays, 2.30 p.m. to 6 p.m. Admission free.

Drawing conventions for laboratory glass apparatus

A new British Standard (B.S. 2774: 1956) has just been issued which recommends conventions for drawings of laboratory apparatus, principally of glass, such as are required for working drawings and for British Standards, textbooks, and technical journals and reports. Account is taken of the recommendations in the latest edition of B.S. 308 *Engineering drawing practice.* An appendix deals with the preparation of drawings for reproduction, often on a reduced scale. It would be a great help to editors and publishers if authors would consult this new standard before submitting drawings of glass apparatus.

British Journal of Applied Physics

Contents of the January issue

CONFERENCE REPORT

Summarized proceedings of a conference on the electron microscopy of fibres—Leeds, January 1956. By C. E. Challice and J. Sikorski.

ORIGINAL CONTRIBUTIONS

The determination of linear distortion in nuclear emulsions. By A. J. Apostolakis and J. V. Major.
The X-ray and γ-ray absorption coefficients of a number of glasses. By D. A. Richardson.
The flow of gas through composite systems at very low pressures. By C. W. Oatley.
An electrical analogue of magnetic domains. By P. F. Davis.
The nature of the emitting surface of barium dispenser cathodes. By I. Brodie and R. O. Jenkins.
A tilting stage method for three-dimensional photoelastic investigations. By H. T. Jessop.
The triple point of carbon dioxide as a thermometric fixed point. By D. Ambrose.
The measurement of the thickness of thin carbon films. By A. W. Agar.
The breakdown mechanism of certain triggered spark gaps. By T. E. Broadbent.
Barium getters and oxygen. By R. N. Bloomer.

NOTES AND NEWS

Correspondence

Scaling of space-charge limited electron-optical systems. From M. E. Haine.
Measurements on alloy-type transistors with varying collector voltage. From D. M. Evans.

New books
Notes and comments

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An introduction to the study of non-linear control systems

By J. F. Coales, O.B.E., M.A., M.I.E.E., F.Inst.P., Department of Engineering, University of Cambridge

Non-linearity is explained and defined by deriving the law of superposition for linear systems and showing that it does not apply to non-linear systems. Non-linearities are inevitable in many control system components but in some cases a virtue can be made of necessity and the performance of a system improved by the use of non-linear damping and in some cases of non-linear gain. The position of non-linearity in the system is important and any general analysis of a non-linear system is exceedingly difficult unless the non-linearity occurs in the forward loop immediately before the load.

Various authors have suggested methods of classification of non-linearities but as yet no generally satisfactory system is available. Various methods of analysis have been worked out but only for low order systems with determinate inputs. These are quite successful but as yet no general method has been developed for the analysis of systems with random inputs.

1. INTRODUCTION

has been said that whereas linearity is a specification which erefore limits the field of activity, non-linearity is a "non-ecification" and the field is unbounded, linearity being a rticular part of it. This is, of course, true and it is therefore cessary to consider what we mean by "non-linear control stems."

1.1 *Conditions for linearity and definition of non-linearity.* view of this it is easiest to first define linearity, since then ny system, component or phenomenon which does not tisfy the conditions laid down will be non-linear. We can nly apply the term non-linear to some system or phenomenon which a quantity, the output, changes when some other uantity, the input, changes. The simple meaning of linearity that if the relationship between output y and input x is lotted the result is a straight line such as PQR in Fig. 1. his will only be the case if

$$y = kx + c \text{ (a constant)} \tag{1}$$

nd it is seen at once that if y_0 is the value of y at P where $= x_0$ the value at Q where $x_1 = x_0 + a$ is $y_0 + l$ where

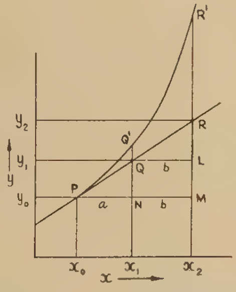

Fig. 1. Linear and non-linear characteristics

$= ka$ and at $x_2 = x_1 + b$ is $y_1 + m$ where $m = kb$. If ve now transfer the origin to P making $x_0 = y_0 = 0$ we have

$$y_1 = l = ka \qquad y_2 = m = kb$$

nd $$y_1 + y_2 = ka + kb = k(a + b) = k(x_1 + x_2) \tag{2}$$

If we write $y = f(x)$, we now have that

$$f(x_1) + f(x_2) = f(x_1 + x_2) \tag{3}$$

nd this is the law of superposition that if we know the output or an input a and also for an input b then the output for an nput $c = a + b$ is always the sum of the outputs for a and b. This is the essential condition for linearity and it is seen from the figure that if the relationship between y and x is not a straight line as at $PQ'R'$ then this does not hold, for suppose we make $y = x^2$ then we should have $y_1 = a^2$, $y_2 = b^2$ and $y_1 + y_2 = (a + b)^2$ but $a^2 + b^2 \neq (a + b)^2$ and so

$$f(x_1) + f(x_2) \neq f(x_1 + x_2)$$

It is also clear that if the output is proportional to the input the process must be linear for if $y_1 = kx_1$, $y_1 + y_1 = kx_1 + kx_1$ or $2y_1 = 2kx_1 = k(2x_1)$ and so on and we have

$$kf(x) = f(kx) \tag{4}$$

Linear systems are not confined to those in which there is a direct relationship between y and x where these are real variables, but it is extended to all functions for which the law of superposition holds and these may include derivatives and integrals.

1.2 *Definition of control system.*—For the purpose of this article it is proposed to define a control system as a network the output of which is some known function of the input, this relationship being maintained to any desired accuracy by comparing with the input, either continuously or at intervals, the output or some function of it. In other words there must be a feed-back path as in Fig. 2.

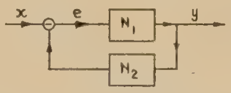

Fig. 2. Block diagram of closed loop control system

The input, the instantaneous value of which we will designate by x, will in general be a function of time $x(t)$. This is compared with some function N_2y of the output y, also a function of time, $y(t)$, and the difference $x - N_2y$ we will designate by e, so that we have the fundamental equations

$$\left.\begin{array}{ll} & y = N_1e \\ \text{and} & e = x - N_2y \\ \text{yielding} & x = (1 + N_2N_1)e \end{array}\right\} \tag{5}$$

$$\text{or} \quad \left.\begin{array}{l} y = N_1x/(1 + N_2N_1) \\ e = x/(1 + N_2N_1) \end{array}\right\} \tag{6}$$

These equations are, of course, well known to all control engineers since they apply to all feedback systems and are easy to use in the linear case when N_1 and N_2 are linear operators, usually resulting in a linear differential equation relating y to x of the form

$$a_n\frac{d^ny}{dt^n} + a_{n-1}\frac{d^{n-1}y}{dt^{n-1}} + \ldots a_0y = b_m\frac{d^mx}{dt^m} + \ldots b_0x \quad (7)$$

Such a characteristic equation results in an output $y(t)$ for a given input $x(t)$ where $y(t)$ is clearly a different function of time from $x(t)$. If now at time $t = 0$ both input and output are zero and immediately after time $t = 0$, a step impulse x_1 is applied, the output may be observed to be of the form shown at y_1 in Fig. 3. If a larger step, x_2, has been applied, an output y_2 would have been observed and if a step $x_1 + x_2$ had been applied, it follows from the superposition law that an output y_3 would have been observed, which is the sum of y_1 and y_2, provided the system is linear, which, as can be shown, will be the case if all the coefficients in equation (7) are constant.

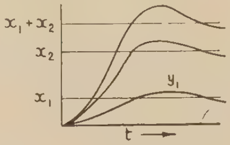

Fig. 3. Step response

It is often more convenient to consider the response of the system to a very short impulse [Fig. 4(*a*)], in which case, provided the duration is short compared with the response of the system, the output $y(t)$, which will be of the form shown in Fig. 4(*b*), will be only dependent on the area of the impulse $= \int_{t_0}^{t_0+\delta t} xdt$, as a result of the superposition law. Unit impulse is defined as one for which $\int_{-\infty}^{\infty} xdt = 1$ and, if we have a number of impulses of the same width but changing height, it is evident that the responses due to them individually will be proportional to their respective heights. Further if we combine these impulses as in Fig. 5(*a*) in order to get the output $y(t)$ we shall have to add together the outputs which will be obtained from each impulse, the responses being the same in shape but the heights being proportional to the heights of the impulses. Any smooth input which is a function of time $x(t)$ can be represented by a series of impulses if we make the duration δt short enough and so we can arrive at the output for any input $x(t)$. Further if $h(t)$ is the response of the system for unit impulse, from the proportionality law, if the area of the first impulse is $x_0\delta t$, the output for this impulse will be $x_0\delta t \times h(t)$. For the next impulse it will b $x_1\delta t \times h(t)$ and so on. But the response to the impuls $x_1\delta t$ starts time δt after that of $x_0\delta t$ so when we add the tw responses we must add $x_1\delta t \times h(t - \delta t)$ to $x_0\delta t \times h(t)$

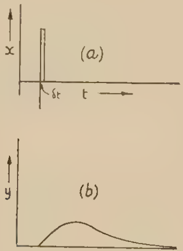

Fig. 4. Impulse response

(*a*) Input
(*b*) Output

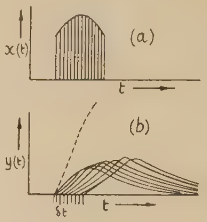

Fig. 5. Super position of impulse responses

(*a*) Input
(*b*) Output

Similarly we can go on adding the effect of the furth impulses x_2, x_3, etc., and we get that the total response $y(t)$ is given by

$$y(t) = x_0h(t)\delta t + x_1h(t - \delta t)\delta t + x_2h(t - 2\delta t)\delta t + \ldots$$

$$= \sum_{n=0}^{N} x_nh(t - n\delta t)\delta t \quad (8)$$

where $\qquad t = N\delta t$

as indicated by the dotted line in Fig. 5(*b*). But x_0 is the value of $x(t)$ at t_0, x_1 is value at $t_0 + \delta t$ and so on and if we consider the value of $y(t)$ at time $\tau = N\delta t$ it will be

$$\begin{aligned} y(\tau) &= x_0h(\tau)\delta t + x_1h(\tau - \delta t)\delta t + \\ &= x(t_0)h(\tau)\delta t + x(t_0 + \delta t)h(\tau - \delta t)\delta t + \ldots \\ &\quad + x(t_0 + N\delta t)h(\tau - N\delta t)\delta t \end{aligned}$$

which in the limit if we make $\delta t \to 0$ becomes

$$y(\tau) = \int_{t_0}^{\tau_0+\tau} x(t_0 + t)h(\tau - t)dt,\ t = n\delta t$$

or putting $t_0 = 0$, $y(\tau) = \int_0^{\tau} x(t)h(\tau - t)dt$ and changing the variable we get that the output $y(t)$ at time t is

$$y(t) = \int_0^t x(\tau)h(t - \tau)d\tau \quad (10)$$

which is known as the "convolution integral." We normally think of $x(t) = 0$ up to $t = 0$ so that we can write this in the more general form

$$\int_{-\infty}^{t} x(\tau)h(t - \tau)d\tau$$

1.3 *Sampled systems.*—It now becomes clear that if instead of applying a continuous output $x(t)$ to the system we only apply samples of the input function whether at regular or irregular intervals, the output responses will add in the same way as before, provided the system itself is linear and therefore the super-position law applies, so that the output will be a linear function of the input whether sampled or not, but the interpretation will depend on the intervals at which the input is sampled.

1.4 *Systems with time-varying parameters.* It further follows that if the system changes with time this only has the effect of altering the impulse response $h(t)$ with time so that it becomes a new and more complicated function, but e superposition law still holds and the form of the con- olution integral is unchanged, so that the system and its aracteristic equation are still linear.

1.5 *Non-linear control systems.* If now we have a non- ear component in the loop of Fig. 1 such that $y = NX$ here $X = f(x)$ as in Fig. 6 in which the impulse response of e remainder of the system is $h(t)$ we have

$$X = f(x) \text{ and } y = N_1 X$$

$$y(t) = \int_0^t X(\tau)h(t-\tau)d\tau$$

$$= \int_0^t f[x(\tau)]h(t-\tau)d\tau \qquad (11)$$

hich is not easily evaluated since $f[x(\tau)]$ is a function of a inction. It is the occurrence of this function of the input inction in the convolution integral, which is characteristic of non-linear system.

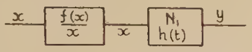

Fig. 6. Open loop non-linear control system

Equation (11) gives the response of an open loop system ontaining an instantaneous non-linearity. This is the mplest non-linear case possible since, in general, non- nearities are time-dependent, as is discussed later in ections 2.2 and 5 in which case it can be shown that the esponse $y(t)$ is much more complicated and will include ulti-way integrals. Similarly, if we close the loop by a edback path in accordance with our arbitrarily chosen efinition, as in Fig. 7, we then get the equations

$$e(t) = x(t) - y(t)$$

$$y(t) = \int_0^t f[e(\tau)]h(t-\tau)d\tau$$

$$= \int_0^t f[x(\tau) - y(\tau)]h(t-\tau)d\tau \qquad (12)$$

nd it is seen that we no longer have an explicit expression or the output in terms of the input, and the output can only e obtained in general by the solution of an integral equation.

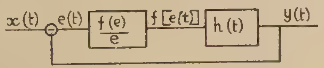

Fig. 7. Closed loop non-linear control system

t present no general method is available of solving the ntegral equations which arise in either the open-loop case ith time-dependent non-linearities or in even the simplest ase of a closed-loop system. It will be shown later in Section .4. that if the non-linearity is in the feedback path the problem still more intractable and time-dependent non-linearities omplicate it still further. Approximate methods of solution ave been worked out and their application will be discussed Section 5.

With linear systems⁽¹⁷⁾ a knowledge of the transient response o a step or impulse input can tell us the frequency response f the system and *vice versa*. Further, knowing the frequency esponse for a linear system we can estimate the performance for a random input if we know its power spectrum. With a non-linear system however, this cannot be done because the law of superposition does not apply and the response of a system as a whole is dependent on the amplitude of the input.

It is an essential feature of non-linear systems that if the input is a pure sinewave the output will always contain harmonics and the waveform of the output will be a function of the amplitude as well as of the frequency of the input.

It may be that in some applications the performance can be considered for small rapid changes of input about a slowly varying mean, in which case the system may be sensibly linear for the small changes and analysis may be achieved by the method of small perturbations,⁽¹⁶⁾ but in general this will not be possible. We have seen that for a sinusoidal input the output of a non-linear system will always contain harmonics, so that the quantity $x(t)$ (Figs. 5 and 6) will always include some higher harmonics of the input. Any physical system contains inertia to a greater or less extent and for this reason it is usual for that part of the system indicated by $h(t)$ in the figure to behave as a low-pass filter. It will therefore be usual for the higher harmonics to be attenuated before reaching the input *via* the feedback path. This suggests that as a first approximation the output for a sinusoidal input should be assumed to have no harmonics, which is the basis of the describing function methods of analysis discussed later in Section 6.1, which result in a knowledge of the frequency response of the system for different amplitudes.

If harmonics in the output are neglected then an instantaneous non-linearity can be considered as a variable gain dependent only on the rate or mean frequency of the input, and this is the approximation proposed by Booton,⁽¹³⁾ further described in Section 6.3.

2. NON-LINEARITIES THAT CANNOT BE AVOIDED

We have limited the field of non-linear phenomena very considerably but we can still have any conceivable type of non-linearity included in either the forward or the feedback loop. We must therefore consider in what types of non-linearity we are interested. These we can divide into two main classes, those which occur in control systems inevitably, and those which are interesting in that they may be intentionally included in the system in order to improve the performance.

2.1 *Occurrence of non-linearity in control system components.* In order to classify the unavoidable non-linearities occurring in control systems it is convenient to divide up the forward loop, transform N_1, into a number of component parts as shown in Fig. 8. Considering these in order: if we have to work with the highest possible sensitivity of error, the comparator will almost certainly be non-linear, most known detectors being square-law for very small inputs. If we do not have to work near the limit of sensitivity then the comparator can often be used in a linear range. The amplifier, which, since a high gain is always necessary in the forward loop, is an essential part of any system though it may be included in one of the other components, will saturate at some level. It is usually possible in design to ensure that saturation does not occur within the working range of $e(t)$

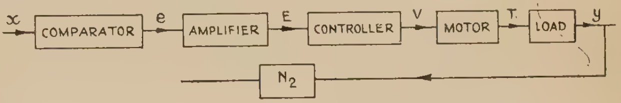

Fig. 8. Components of a control system

for the system and curvature within this range can usually be reduced to insignificance by local feedback but both of these requirements necessitate more generous design and may therefore be uneconomical.

The design of the controller will, in general, be entirely in the hands of the system designer and will only include non-linearities if these are desired to improve the performance of the system as a whole. Such non-linearities are therefore considered to be voluntary and are included in the next section.

The motor can be linear over a given range but will, in general, have a curved torque/input characteristic and in any practical system there must be some upper limit to the output torque. As in the case of the amplifier, limitation of the working range to an essentially linear range may necessitate a very extravagant design. Feedback can, of course, usually be used to linearize the torque-input characteristic, but is usually extravagant in design and may necessitate a subsidiary loop.

Clearly little can be said about the characteristics of the load except that in any physical system it must have inertia and must therefore have a transfer function that is at least second order and it may include any of the common types of non-linearity. (Under certain conditions as in a speed control system, the error signal may be a rate in which case the transfer function will only be first order, provided higher derivatives than acceleration do not become important.) As we shall see later, the importance lies in the position in the system of the non-linearity.

Mention must also be made of the connecting links or transmission between the components, which, in any system including mechanical gearing, must include some degree of backlash and in the more general case hysteresis. Further, any gearing will exhibit errors of manufacture, which introduce non-linearity of input/output characteristic, but it is usually possible to reduce these errors and backlash to a negligible magnitude provided this is not too expensive.

In general, the feedback loop is entirely under the control of the designer with the exception of the transmission itself and need not include any non-linearity. It should be noticed that in any practical cases not only will the motor torque be limited but also all derivatives of it, from which it follows that whereas over some range the characteristic must be non-linear, it must always be a regular function of time, even if not of the input. (A regular function of a variable is one for which all derivatives are finite and continuous.) This, in fact, applies to all practical components and so also to the input and the output as functions of time.

2.2 *Time-dependent non-linearities.* The non-linearities mentioned in the preceding section have all been instantaneous, but in practice non-linear characteristics such as those experienced in motor-load combinations are liable to be time-dependent, either the motor torque T or the output y being related to the motor input V by a non-linear differential equation of the form

$$f(T, \ddot{T}, \dot{T}, \ldots T^{(n)}, V) = 0 \qquad (13)$$

More is said in Section 5 of non-instantaneous non-linear devices, so suffice it to point out here that biological control loops apparently include parts belonging to this class and electric circuits including non-linear components (resistors, capacitors or inductors), are also essentially time-dependent.

3. NON-LINEARITIES WHICH MAY BE INCLUDED TO IMPROVE THE PERFORMANCE

Clearly there are unlimited possibilities that might be tried and until we have some means of estimating the performance of non-linear systems little can be said of what types of non-linearities are going to prove most useful. It can, however be forecast on purely general grounds that certain non-linearities can be used to improve performance and something can also be said of where they should be included Further, it is evident that the practice of making each component work only in a linear part of the range is usuall extravagant in design and therefore an attempt must b made to make use of such non-linear characteristics a arise. Three examples of desirable non-linearities are give below.

In nature, non-linearity is the rule rather than the exception and linearization has in general only been a device used b man to enable him to analyse what occurs in nature. A such it more properly belongs to the realm of physics than engineering. Most practical components used in contro systems are essentially non-linear and in many applications particularly in the realm of communication engineering, it i the non-linearities rather than the linearities which are mos used. In the realm of nature, non-linear mechanisms hav been discovered and are being investigated. Since these non-linear systems are the result of millions of years of evolution there is a *prima facie* case that they will be the most efficient and economical. It is likely, therefore, that they will repay study and simulation in the field of engineering.

Experience indicates which non-linearities are likely to be useful. On general grounds, our experience of linear systems leads us to the conclusion that certain simple types of non-linearity will be beneficial; for instance:

3.1. *Non-linear damping.*(1) With linear systems it has been found that under most conditions the best response is obtained when under-damped, the coefficient of damping being about 0·6. If, however, as the system approaches zero error, the damping can be increased, it can be made to run into step more quickly without overshoot, thereby improving the performance.

3.2 *Non-linear gain and non-linear damping.* If we have a system which we assume to be running initially without error, but which has random noise imposed on the input likely to obscure the error signal, then on general grounds we apparently need the highest possible restoring force for small error signals, but since large gain will make the system unstable, we need to apply high damping in addition. In other words, for small error signals we want a small band-width and a long time-constant, which reduces the noise power and increases the smoothing. On the other hand, if there is a large disturbance, though we still want a high gain, we no longer want high damping because the system should run into line as quickly as possible and there is no danger of overshoot until alinement is approached, and when the required signal is bigger than the noise, the long smoothing time is not required. If the gain remains high for large input signals, this requires high output power, the provision of which will be uneconomical if the system is usually running with only small error. It therefore appears that the ideal system under these conditions would have non-linear restoring force and non-linear damping.

3.3 *On/off controller with dead-zone.* From the practical point of view the performance of any servo-system is usually limited by the maximum output torque or output power which is available. Under these conditions, if there is an error between input and output this will be reduced to zero in the shortest possible time when the output is first accelerated as rapidly as possible and then decelerated as rapidly as possible, provided the changeover is made at the right time for the output to come into step with the input. This can be one with a perfect on/off$^{(2,3)}$ controller, but results in the otor driving the load operating at full power all the time, rst in one direction and then in the other. Thus, though e system is economical in motor size it is uneconomical in ower consumption when the input is only changing slowly. ', however, a small error is permissible and the on/off ontroller can be arranged to have a dead-zone of twice this ror then, when the error has been reduced to this amount, e motor is switched off and is not switched on again until e input has moved sufficiently for the error to be again utside the limits of the dead zone. Thus, if properly rranged, the motor will always drive the load in such a ay as to reduce the error to less than half the dead-zone the shortest possible time and when the error is within the ead-zone the motor will be switched off and no power ill be consumed. It appears, therefore, that this, if practicble, would be the most economical system from the point f view both of motor size and power consumption.

. THE POSITION OF THE NON-LINEARITY IN THE SYSTEM

4.1 *Non-linearity in forward loop external to the load.* rom the point of view of analysis the position of the on-linearity in the system is important. Consider the simple ase of Fig. 9 in which the non-linearity occurs in the motor, ut is instantaneous so that it can be separated from the linear art of the motor characteristic, inertia, damping, etc., which an therefore be combined with that of the load, in this case ssumed to be linear and of second order.

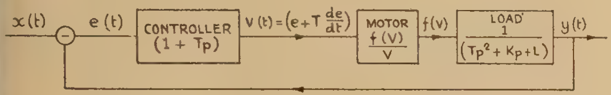

Fig. 9. Control system with non-linear motor

We can then write down

$$\left.\begin{aligned} V &= \left(e + T\frac{de}{dt}\right) \\ f(V) &= J\frac{d^2y}{dt^2} + K\frac{dy}{dt} + Ly \\ e &= x - y \end{aligned}\right\} \qquad (14)$$

nd eliminating X and V we get

$$\frac{d^2e}{dt^2} + \frac{K}{J}\frac{de}{dt} + \frac{Le}{J} + f\left(e + T\frac{de}{dt}\right) = \frac{d^2x}{dt^2} + \frac{K}{J}\frac{dx}{dt} + \frac{Lx}{J} \qquad (15)$$

4.2 *Simple instantaneous non-linearity in the load.* If, owever, the non-linearity occurs in the load itself quite a ifferent situation arises for we must now consider the non-inearity, still instantaneous, to come after the linear transfer unction of motor and load as in Fig. 10.

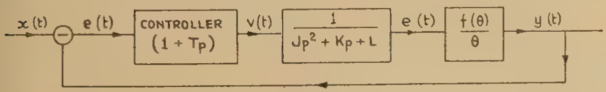

Fig. 10. Control system with non-linear load

as before

$$\left.\begin{aligned} V(t) &= e + T\frac{de}{dt} \\ e &= x - y \\ V(t) &= J\frac{d^2\theta}{dt^2} + K\frac{d\theta}{dt} + L\theta \end{aligned}\right\} \qquad (16)$$

but now

$$y = f(\theta)^* \qquad (17)$$

again eliminating V and X we get

$$J\frac{d^2\theta}{dt^2} + [K + Tf'(\theta)]\frac{d\theta}{dt} + L\theta + f(\theta) = x + T\frac{dx}{dt} \qquad (18)$$

where

$$\frac{(1 + pT)}{Jp^2 + Kp + L}e = \theta$$

where p is the operator d/dt.

This characteristic equation can only be written conveniently in this form and must be first solved for θ.

4.3 *Simple instantaneous non-linearity in the feedback loop.* If the non-linearity is in the feedback path as in Fig. 11

then as before

$$\left.\begin{aligned} V &= e + T\frac{de}{dt} \\ \text{but now} \quad V &= J\ddot{y} + K\dot{y} + Ly \\ e &= x - f(y) \end{aligned}\right\} \qquad (19)$$

$$\frac{de}{dt} = \dot{x} - f(y)\dot{y}$$

$$x - f(y) + T\dot{x} - Tf(y)\dot{y} = J\ddot{y} + K\dot{y} + Ly$$

$$J\frac{d^2y}{dt^2} + [K + Tf(y)]\frac{dy}{dt} + Ly + f(y) = x + T\frac{dx}{dt} \qquad (20)$$

where

$$y = \frac{(1 + pT)}{(Jp^2 + Kp + L)}e$$

which gives the same solution as before.

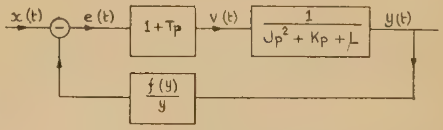

Fig. 11. Control system with non-linear feed back

4.4 *Compound non-linearity in load or feedback loop.* In Sections 4.2 and 4.3 only a simple non-linear amplitude characteristic has been considered but clearly the load or feedback path may introduce non-linear functions of the derivatives. Under these conditions the most general second-order case will be expressed by

$$V(t) = F(y, \dot{y}, \ddot{y}) \qquad (21)$$

and so

$$\begin{aligned} e + T\frac{de}{dt} &= F(y, \dot{y}, \ddot{y}) \\ &= F[(x - e), (\dot{x} - \dot{e}), (\ddot{x} - \ddot{e})] \qquad (22) \end{aligned}$$

In most cases, however, V will be a linear function of the second derivative of x, the assumption being that the inertia is constant. In this case equation (21) can be written

$$V(t) = J\ddot{y} + f(y, \dot{y}) \qquad (23)$$

---

* This only applies in the very simple case considered. The more general case is given in Section 4.4 and a valve controlled hydraulic component is a common example of the more general case.

and the load can be represented by a linear filter and an instantaneous non-linear element, provided

$$f(y, \dot{y}) = \frac{K}{J}a(x)\ddot{x} + \frac{K}{J}a'(x)\dot{x} + L\int^{x} a(x)dx + \text{constant of integration} \quad (24)$$

A non-linear device in the feedback path yields exactly similar expressions.

4.5 *The importance of the physical position of the non-linearity.* It is important to notice the difference between the characteristic equations because only in the first case have we got an explicit equation giving the error e in terms of the input x. This will be seen to be important when we come to consider phase-plane methods and random inputs. In this case not only shall we usually have the non-linearity under our control but will be able to combine compensating networks with it without complicating the characteristic equation. When, however, the load itself is non-linear in response to the applied torque then not only is it unlikely to be under our control, but as is seen from equation (18) no explicit equation for e in terms of x is available and a solution must be obtained in terms of θ from which e can be obtained.

Now in general the performance of a control system is judged by the magnitude and behaviour of the error e with respect to the input x and unless the output y follows the input x within reasonable limits the system will be deemed unsatisfactory and except for devising means of improving it we shall be no longer interested in it. Thus, for any sensible system the error $e(t)$ will be bounded and the limits will be small compared with those of $x(t)$ and $y(t)$. It is not possible to say that the limits of $\theta(t)$ will be small compared with those of $x(t)$ and $y(t)$ and so we have no direct measure of the error function $e(t)$ when the non-linearity is in the load or feedback loop. Adding a compensating non-linear network in general only complicates the equation.

5. TYPES OF NON-LINEARITY

A word must now be said about types of non-linearity. In the systems considered so far the non-linearity has been considered to be instantaneous, so that the output is not delayed relative to the input, as will be the case with an amplifier of dynamic response fast compared with the changes of the input. If we have a resistor of which the resistance changes with the voltage applied to it

$$\text{then if} \qquad R = f(V),\ I = \frac{V}{R} = \frac{V}{f(V)} \qquad (25)$$

and if we consider I to be the output for an input V we have a non-linear characteristic which is instantaneous. If, however, the resistance is dependent on temperature, $R = f(T)$ and the energy dissipation equation is given by

$$\frac{V^2}{R} = Q\frac{dT}{dt} + KT \text{ or } V^2 = \left[Q\frac{dT}{dt} + KT\right]f(T) \quad (26)$$

which must first be solved for T before the current I can be calculated from $I = V/f(T)$. In this case it will be seen that the non-linearity is not instantaneous and there is no obvious way of dividing it up into an instantaneous non-linearity and a linear filter (having time-delay).

Zadeh(4) has proposed a classification of non-linearities in mathematical terms which divides them up into very broad classes on the basis of characteristic functions which are the equivalent of the weighting functions of linear systems. This might well assist the simulation of systems for work on random inputs but in control system work the difficulty is that unless the characteristic equation of the closed loop can be solved the characteristic function is unknown and the appropriat class cannot be determined.

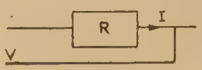

Fig. 12. Time-dependent non-linearity

Cherry(5) on the other hand has proposed classification on the basis of well-known types of non-linearity (mostly instantaneous) experienced in practice, which ideally are not analytic functions (although in their physical embodiments they must be on account of inertia) and therefore solution of systems involving them can only be obtained by graphical or piecewise linear methods. Cherry has divided instantaneous non-linearities into two classes, simple and non-simple; simple non-linearities being those in which the output is always a single-valued function of the input, examples being limiters and perfect on-off controls with or without dead-zone; non-simple non-linearities being those in which the output is not single-valued as in systems with backlash or hysteresis. This distinction is of importance because for a simple non-linearity, the describing function is real but for a non-simple it is complex.(9, 10)

Cherry only considers non-linearities which are symmetrical, in which the output is an "odd" function of the input, i.e. there are no even harmonics, but clearly in the more general case the output will not be symmetrical and therefore not a "odd" function of the input (an example being a loaded on-off control). Such non-linearities may be termed unsymmetrica the symmetrical ones making a sub-class of the more general class of instantaneous non-linearities.

A further distinction must be made between non-linear elements in which the output is a function of a single input and those in which it depends on some other variable in the system, as in the case of a self-optimizing or sympathetic servo. A torque-limited motor is an example of the first class, but a power-limited one is of the second class, since it interacts with the output velocity. These classes may therefore be termed non-interacting and interacting respectively.

Narrowing the gap between these two suggestions is an important requirement.

Cherry and Miller(6, 7) have developed some rules based on energy considerations for the investigation of electrical networks containing non-linear elements which are essentially time-dependent, non-linear systems.

6. METHODS OF SOLUTION

As is well known no general method of solution is available for non-linear differential equations and this is still the case even when the field has been narrowed by definition as in Section 1, and arbitrarily as in Section 2. At this stage one further way of limiting the field must be mentioned, that of the stability criterion. If we are designing a control system in the sense of Section 1, we shall certainly be able to lay down some criterion of stability which it must fulfil and any system which does not fulfil this criterion is then of no interest and further analysis of it is unnecessary, except as a guide to modifications which may lead to stability. This is the great power of topological methods, since phase-plane and acceleration-plane diagrams are in general easily constructed and yield immediate information concerning stability, and it can be shown that this information can even be applied to systems with random inputs.(15)

6.1 *Describing function methods.* Describing function ethods(8, 9, 10, 16) have been widely used in recent years for e investigation of non-linear control systems. These are sentially frequency response methods in which it is assumed at the system behaves as a low-pass filter and that at the tput all harmonics of the input frequency other than the ndamental are of such small amplitude that they can be glected. This will usually be true where there is a large wer amplification between input and output but is certainly t true of many closed loop control systems used in analogue mputing. An extension of the usual describing function ethods has been developed to obtain the transient response a non-linear system.(11)

6.2 *Piecewise linear methods.* Piecewise linear methods of lution may well be very generally applicable to the types of stantaneous non-linearity most usually met in control stems. They are particularly applicable to relay controls, it can also be applied to more complicated systems.(12) ne great advantage of these methods is that the response a very large range of different systems to step and ramp nction inputs can be quickly determined by the use of a nall number of previously prepared charts.

Piecewise linear methods are also useful in connexion with ndom inputs since they provide a possible method of termining the performance of a system in terms of the atistical content of the input. An integral equation always sults but this can probably be evaluated by numerical ethods. Integral equations are an essential feature of any tempt to estimate the performance of a non-linear system ith random input and numerical methods of solution may ten be the only possible method of solution.

6.3 *Systems with random inputs.* Since for non-linear stems the principle of super-position does not apply, it is t possible to predict the performance of such a system for ndom inputs from the known response to step-functions of nusoidal inputs. In the case of linear systems, if the per-rmance is known in terms of step-function this can be nverted into the frequency response and *vice versa*, and the ork of Wiener has shown how the performance for a random put can be calculated from the frequency response provided e frequency spectrum or auto-correlation function of the put is known. Thus the design of control systems to fulfil e-determined criteria under conditions of random input s become possible for linear systems even in the presence unwanted disturbances or noise, but as yet no general ethod has been found of doing this for non-linear systems. me attempts have been made to do this by the use of proximations, but so far only for instantaneous non-nearities. Booton(13) has obtained some results by dividing e non-linear characteristic into a linear part and what he lls the "distortion factor." He then adjusts the slope of e linear part to give the best fit on a mean-square-error sis and the "distortion factor" is neglected. Though this a very gross approximation it has been found to give good reement between theory and experiment in a number of actical examples.

A method developed by Burt(14) allows a Wiener type timization to be carried out by assuming that the prob-ility distributions are gaussian at all points in the system, that spectral densities can be used to obtain a solution. Of urse the output from a non-linear component having a ussian input is non-gaussian and the essential approxi-ation is to assume a gaussian distribution with a simple ectral density of the same area as that of the non-gaussian tput obtained from the non-linear component.

A mathematical justification for these approximations has been developed and is given in a paper by Barrett and Coales.(15) So far no general method of analysis or synthesis has been found which is applicable to systems containing time-dependent non-linearities.

7. CONCLUSIONS

It has been shown that provided the non-linearities are instantaneous and occur in the forward loop and external to the load they are under the control of the designer of the control system and can be used to advantage in improving the performance. Under these conditions the governing equation of the system is simple and can be solved by numerical methods. If, however, the non-linearity is in the load or the feedback path, the governing equations are complex even for instantaneous non-linearities and the solution is by no means simple. With time-dependent non-linearities the governing equations are still more complicated and as yet, in general, no methods of solution are available. This does not mean that non-linear systems and non-linear components cannot be used with advantage for automatic control, in fact as has been said in Sections 2 and 3, linear systems are almost always uneconomic in design and non-linear systems can clearly have great advantages over linear ones, if we can but design them to suit our requirements. Methods for the approximate design of simple non-linear systems on the basis of step-functions and sinusoidal inputs have been developed, e.g., describing function and piecewise linear methods. The most urgent problem now is to devise general methods of analysis and synthesis (including optimization) of simple non-linear systems with random inputs and eventually of more complicated systems including time-dependent non-linearities.

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A sensitive photoelectric polarimeter

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The construction of a simple photoelectric polarimeter is described. The instrument has a sensitivity considerably higher than the usual visual type but with a more restricted range. Features of the instrument which make for convenience in operation and also to which attention must be paid in order to use fully the intrinsic sensitivity of the system are outlined.

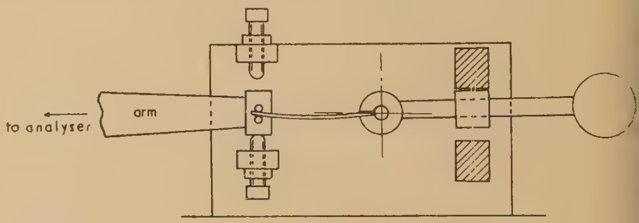
The conventional type of visual polarimeter used in most laboratories suffers from a number of disadvantages. For accurate work, the observer needs to be dark-adapted and consequently a dark-room is necessary. In addition, the sensitivity is not particularly high and often necessitates the use of a long specimen tube. The volume of liquid required is then considerable, and if the solution is at all coloured or turbid the sensitivity of the instrument is reduced. These considerations make observations tedious and sometimes difficult and may well limit the application of polarimetric methods in certain fields. It was therefore thought worthwhile to develop a simple and accurate polarimeter using a photomultiplier tube as the detector which might overcome some of these difficulties. There have been a number of descriptions of various types of photoelectric polarimeters(1–5) in recent years, of varying degrees of complexity. Many follow the photomultiplier with one or more stages of electronic amplification: this appeared unnecessary and only an attachment for a normal commercial instrument described by Rudolph(5) attains the simplicity and sensitivity of the present instrument. By building the entire instrument rather than adapting existing commercial models, the full advantages of the higher sensitivity and accuracy obtainable with a photomultiplier detector can more readily be attained.

DESCRIPTION

The general arrangement of the instrument is as follows. A lamp illuminates a pinhole which is at the focus of an achromatic lens. This provides an (approximately) parallel beam of light which passes through the polarizer, the cell and the analyser and falls on the photomultiplier. A shutter is provided to protect the photocell, and a mirror which can be lowered at 45° to the beam to look along the beam by eye. This is very useful for examining the solution and detecting birefringence in the cell windows, in stray particles or arising from the nature of the solution. An approximate extinction can also be found very quickly by eye.

The polarizer and analyser are both polarizing filters as supplied by Cooke, Troughton and Simms Ltd. in strain-free mountings for use in polarizing microscopes. These are mounted in the centres of ball-races, taking care to use a method of holding them in place which does not introduce any strain in the system. The polarizer is rotated by an arm with a ball-bearing in the end, which is loaded by an extension spring against the anvil of a 25 mm/micrometer head. It is arranged so that the line joining the centre of rotation of the polarizer bearing to the end of the ball is at right angles to the micrometer axis when the micrometer is set in the middle of its scale. If the length of this arm is 18·85 cm the micrometer reading in centimetres multiplied by three gives the rotation in degrees, and rotations of $\pm 3\cdot6°$ can be measured. Should the rotation be higher than this a shorter cell can b used.

The analyser is mounted so that it can be rotated throug a pre-set angle by an arm as shown in the figure. Th rectangular steel block on the end of the arm carries tw pairs of short steel rods between which two strips of phospho bronze $\frac{1}{32} \times \frac{1}{8}$ in. are just free to slide. These are rotated b moving the handle on the right up or down so that they pres the steel block on the pre-set screws. To obtain a quic changeover a piece of soft iron can be mounted on the arm connected to the handle so that it moves between the poles o a permanent magnet (shown shaded).



Mechanical arrangement for the rotation of the arm connected to the analyser

All the components are mounted on a cast-iron base for mechanical rigidity and enclosed in a light-tight case Apertures are provided in the top for viewing the mirror and placing the cell in position. For use by non-technica personnel it is desirable to have an interlock device to preven the instrument being opened unless the shutter is closed.

The photomultiplier is an E.M.I. type 6094 B tube run either from a stabilized power supply or batteries and the output is observed on a Cambridge spot galvanometer with a sensitivity of 170 mm/μA. Provision is made for backing off the galvanometer. Other types of phototube may be satisfactory but the method of construction of those made by E.M.I. Electronics Ltd. should make the sensitivity independent of the direction of polarization of the incident radiation. It is very desirable that the photo-cathode should be as uniform in sensitivity as possible, since errors will occur on this account if the polarizers are non-uniform.

The supply for the lamp should also be stabilized. The authors have used a 45 W sodium discharge lamp in the "end-on" position to obtain increased brightness. This illuminates a pinhole of adjustable diameter; about $\frac{1}{16}$ in. is convenient for most work. A certain amount of light may come out of the end of the glass of the polarimeter tube itself, which will give a large standing signal. To eliminate this a stop slightly smaller than the diamater of the tube should be fitted on the end nearest to the photomultiplier.

In operation, the micrometer head is adjusted so that the gnals in either position of the arm are equal. If θ is the igle between the direction of polarization of analyser and larizer the transmission I is proportional to $\cos^2 \theta$ plus a nstant small amount depending on the quality and optical nsity of the polarizing filters. Oscillation of the analyser ves two signals which are balanced. The rate of variation I with $\cos^2 \theta$ is a maximum when θ is ±45°; this, however, not the optimum angle for the rotation of the analyser nce there is then a very large signal on the photocell and e accuracy is limited by the stability of the source. For clear lutions, an angle of ±1° or 2° is sufficient. For narrow re micro-tubes or coloured solutions where the amount of ght transmitted is reduced, this angle can be increased. The oint has been fully discussed by Rudoph.(5) We have found at it is possible to obtain readings to ±0·001° with ease. he absolute accuracy is not as good as this and depends on e quality of the optical components and the uniformity of the photomultiplier surface. We have found, however, that the values for the optical rotation of solutions calculated from the length of the arm on the polarizer and the micrometer reading, agree well with values for the solution on a visual instrument. For coloured solutions, accurate measurements can be made where any reading is impossible on a visual instrument.

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A precision paramagnetic resonance spectrometer

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An instrument is described for the accurate comparison in the same magnetic field of the frequency of electronic magnetic resonance absorption, particularly in gaseous materials, with the frequency of proton resonance absorption. Details are given of (1) the production of a homogeneous magnetic field, which can be stabilized at any value between 1 and 11 kG; (2) the production and measurement of the radio-frequencies used for the observation of proton resonance in this field; (3) the supply and measurement of a stable microwave frequency in the region of 9000 to 10 000 Mc/s; (4) the sensitive detection of paramagnetic resonance absorption at this frequency using 115 kc/s magnetic field modulation. The precision of the measurements is about three parts per million; it is limited mainly by the homogeneity of the magnetic field, and the measurement of the proton resonance frequency.

1. INTRODUCTION

number of paramagnetic resonance spectrometers are escribed in the literature(1) which have a precision of 100 arts per million (p.p.m.) or less. For measurements on ases, where the line width can be reduced to less than 0 p.p.m., a spectrometer where both the frequency and the nagnetic field can be measured to 1 p.p.m. gives results of recision comparable with that obtained in atomic beam xperiments. In this paper is described a relatively simple pectrometer which fulfils these requirements, and can be sed equally well for the study of solids, liquids and gases; ts performance with gases is analysed. It is similar in rinciple, but not in detail, to that described by Beringer and eald.(2)

2. THE MAGNETIC FIELD

2.1 *The magnet.* The homogeneous magnetic field equired for these experiments is provided by a large double-oked electromagnet, with poles fixed to the centres of the pright sections of the cast iron yoke by four bolts. Between he pole pieces and the yoke are placed thin shims to aline he pole faces approximately parallel; fine adjustments are hen made by controlling the relative tightness of the retaining bolts. The poles, of diameter 28 cm, carry tapered pole tips of magnet steel; these reduce the pole diameter to 22 cm, and have flat ground faces. The pole gap is 4·9 cm.

Each magnet pole carries three separate large coils each of about 1400 turns. The six large coils *A* are connected in series-parallel, and carry the main energizing current, which is derived from the stabilizer described in Section 2.3. The turns on the coils were carefully matched during winding. On each magnet pole there is also a fourth former carrying three separate smaller windings; each pair of similar coils is connected in series. These smaller coils are used to provide relatively small superimposed fields. One pair *B*, of 200 turns, is used to provide the 75 c/s magnetic field modulation required for proton resonance detection (see Section 2.4) and a second pair *C*, of 400 turns, carries the correction current provided by the proton resonance field stabilizer. The largest pair *D*, of 1150 turns, may be supplied with a supplementary direct current derived from the 50 c/s mains *via* a Variac, transformer, rectifier and smoothing circuit. The Variac is automatically driven at one rotation in 7, 15 or 30 min, and this provides a field traverse of 80, 150 or 300 G in each of these times.

2.2 *Field homogeneity.* To examine the homogeneity of the magnetic field, two proton resonance detector heads (see Section 2.4) were fed with the same radio-frequency; the location of one head (the "standard") was fixed, and the other (the "plotter") was moved systematically to explore the field. The method used was to stabilize the magnet current

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(see Section 2.3) at some suitable value, modulate the field with an amplitude of 1 G at 75 c/s using coils *B* and, using an electronic switch, to display the two proton resonance absorption signals on the same oscilloscope trace with a 75 c/s sinusoidal time-base. The separation between the two signals is then proportional to the field difference between the locations of the "standard" and "plotter."

At first there were marked variations in the magnetic field both for axial and for radial displacements from the centre, which were corrected by mechanical adjustments of the magnet. The field contours were then roughly concentric ellipses with their major axes (the direction of minimum variation) vertical; the lack of circular symmetry is presumably due to the yoke above and below. The field at the centre was a minimum, but beyond a radial distance of roughly 5 cm the expected drop off due to the edges of the poles occurred. The size of this central "hole" in the field was up to 400 p.p.m. at 5 kG.

Since the main field inhomogeneity was that caused by the "hole" at the centre, experiments were performed to find out how to reduce its size. It was found that it could be roughly halved by first saturating the magnet in the reverse direction, and then halved again by slowly cycling the field a number of times between zero and the required value in the forward direction [this was accomplished by a cyclic variation of the voltage supplied to a vernier potentiometer (Section 2.3)]; saturating the magnet in the forward direction restored its size to its original large value. "Holes" in the field have also been observed by other workers, including Dellis$^{(3)}$ who pointed out that they could be reduced by slowly cycling the field.

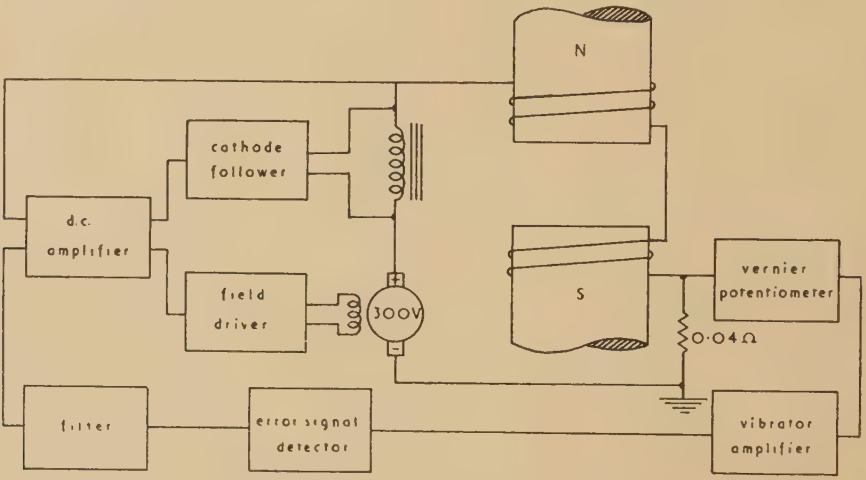

Fig. 1. Block diagram of magnet current stabilizer

After reducing the size of the "hole," the field is usually homogeneous to 5 p.p.m. over practically the whole volume of the sample, a cylinder 3 cm long by 1·3 cm diameter with its axis vertical. This homogeneity persists for a few weeks unless (i) there has meanwhile been an accidental surge in the magnet current, or (ii) a new field has been set up differing from the old by more than a few hundred gauss, in which case the bolts fixing the poles to the yoke require slight adjustment.

2.3 *Stabilization of current.* The current stabilizer is quite similar to that described by Sommers, Weiss and Halpern;$^{(4)}$ for details of the design, reference should be made to their paper. A block diagram of the scheme is given in Fig. 1. The voltage drop across a standard resistor in the magnet current circuit is compared with the potential set u on a vernier potentiometer. Any discrepancy is an erro signal, which is used to correct the output of the moto generator set delivering the magnet current. In addition ripple from the generator is reduced by a second feedbac loop taking its input signal from the magnet voltage.

2.4 *Proton resonance field stabilization.* The curren stabilizer holds the field constant to about 20 p.p.m. for ove an hour. This stability is ample when searching for para magnetic resonance absorption lines by superimposing o this main field a small continuously increasing field supplie by coils *D*, and it is just sufficient not to introduce any seriou error when measuring the field difference between the location of the sample and of the stabilizer proton resonance prob (see Section 2.5). The final stabilization of the field to bette than 1 p.p.m., and also the measurement of the proton resonance frequency, is achieved by means of the syster shown in Fig. 2. The detector head was developed from on used by Beringer and Heald,$^{(2)}$ and consists of a tune receiver supplied with radio-frequency power through a hig impedance. The inductance of the tuned grid circuit of th amplifier stage contains the proton sample (distilled water with a paramagnetic salt added; see Section 4.2); this forms the "probe" which is connected to the "head" by a rigid coaxial line, and is placed in the magnetic field. The field is modulated by about 0·01 G at 75 c/s, causing the output of the receiver to be modulated at this frequency with a phase and amplitude depending on the first derivative of the absorption curve at that point. This signal is then amplified, and fed into a phase-sensitive detector with a long time constant (of the order of one second). The output of this controls the current in coils *C*, thus locking the magnetic field to the centre of the proton resonance line. Since the correction current is proportional to the error, the loop gain of the system must be of the order of 100 to achieve the desired stability; the measured loop gain is roughly 750.

2.5 *Production and measurement of radio-frequencies.* In order to avoid the difficulties involved in making a variable frequency oscillator stable to 1 p.p.m. and tunable over the whole range from 5 to 50 Mc/s, the system shown in Fig. 2 is used. The output of a Clapp oscillator, tunable from 0·5 to 1·0 Mc/s, is mixed with harmonics of 1 and 10 Mc/s obtained from the laboratory frequency standard. The mixing is accomplished in two stages: first the required 1 Mc/s harmonic, which is between 5 and 10 Mc/s inclusive, s combined with the output of the Clapp oscillator in a ridge-ring modulator. Either the sum or the difference requency is selected by a tuned circuit, and this is then nixed with the required 10 Mc/s harmonic in the same way. purious signals are always much smaller than the main one, but are still large enough to cause a troublesome amplitude modulation near the 1 Mc/s markers. The level of modulation on the radio-frequency supply to the proton resonance detector may be reduced to an acceptable value by using the mixer output to control the frequency of a separate locked oscillator. For optimum performance of such a device it is usual to use a phase discriminator, amplifier and reactance valves to control the oscillator frequency. However, a simpler circuit with adequate performance for our purpose has been developed. It uses the tendency of an oscillator to lock on to the frequency of a radio-frequency signal close to the resonant frequency of its tank circuit. In the circuit shown in Fig. 3 the operating conditions have been chosen to exaggerate the locking effect, so that with the values given, and a radio-frequency input of 1 V amplitude, a locking range of 25 kc/s is obtained at a frequency of 25 Mc/s, while the spurious modulation level is reduced by over 20 dB.

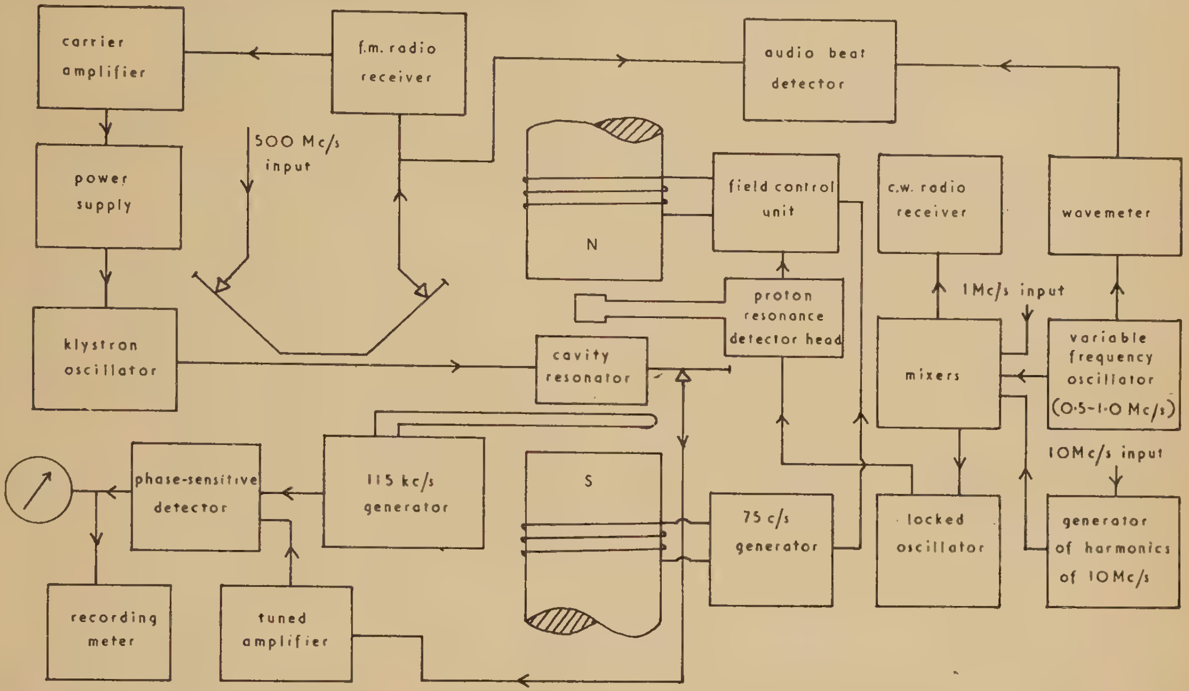

Fig. 2. Block diagram of apparatus: the upper left-hand side shows the microwave frequency stabilizer, the lower left-hand side the detection system, and the right-hand side the proton resonance field stabilizer

For frequency measurement, the Clapp oscillator is provided with a second output which is arranged to be rich in harmonics. Three of these are measured with a Marconi type TF 783 wavemeter. After replacing the internal quartz crystal oscillator with a signal from the frequency standard, the accuracy of the wavemeter is 14 p.p.m. and, by measuring three harmonics, the frequency of the Clapp oscillator is known to about 10 p.p.m. This oscillator usually provides about 1/20 of the total frequency, which is therefore determined to about $\frac{1}{2}$ p.p.m. The magnetic field within the microwave cavity is not quite the same as that at the proton resonance sample controlling the field. The correction is determined by replacing the capsule containing the paramagnetic sample by a second proton resonance probe, and measuring the difference between the proton resonance frequency in this position and that at the position of the stabilizer sample, using phase-sensitive detectors to locate the line centres accurately. During this operation the magnetic field is held constant only by the current stabilizer, and a number of measurements are made at the alternate positions to correct for any small drift.

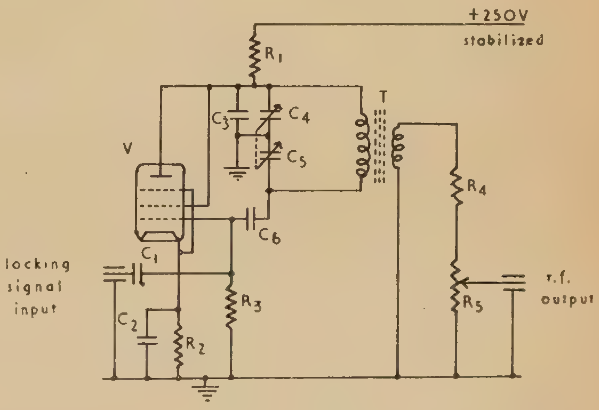

Fig. 3. Circuit diagram of phase-locked oscillator

R_1 = 4·7 kΩ
R_2 = 150 Ω
R_3 = 220 kΩ
R_4 = 220 Ω
R_5 = 100 Ω
C_1 = 5 pF
C_2 = 0·01 μF
C_3 = 12·5 pF*
C_4, C_5 = 100 pF
C_6 = 36 pF
V = 6 AM 6

* Negative temperature coefficient.

T = dust-cored radio-frequency transformer. The primary is to tune to the required frequency with the capacitors C_4 and C_5, and the secondary (2 turns) is to couple about 1V maximum of radio-frequency into the output circuit.

3. THE MICROWAVE SYSTEM

3.1 *Stabilization and measurement of microwave frequency.* A block diagram of the method used to stabilize and measure the microwave frequency is given in Fig. 2. The microwave source is a CV 129 high-voltage reflex klystron operating between roughly 9000 and 10 000 Mc/s. In one arm of an X-band directional coupler is a harmonic generator (G.E.C. germanium diode type GEX 66 biased with a 2 kΩ series resistor(5)) which is fed with about 1 mA of 500 Mc/s current obtained directly from the laboratory frequency standard. The 500 Mc/s frequency has sidebands at ±100 Mc/s and so the harmonic generator produces markers at 100 Mc/s intervals. In the other arm of the directional coupler is a crystal diode mixer which receives these markers and also a small fraction of the klystron power. The beat frequencies are taken to a commercial f.m. receiver (Hallicrafters type S-27D) which is tuned to a beat of less than 100 Mc/s. Any small discrepancy between the beat frequency and the receiver tuning leads to a voltage output from the discriminator; this is amplified and fed as a correction signal to the reflector of the klystron. Since the reflector operates at about −1400 V, a carrier amplifier (operating at about 500 kc/s) is used to provide the necessary high insulation.

To prevent oscillation in the stabilization loop, the loop gain was arranged to be less than unity at 3 kc/s; using for convenience a 6 dB per octave cut, this meant that the gain at 10 c/s is only 300. Furthermore, a frequency correction signal usually produces at the same time an undesirable amplitude variation. It was therefore thought advisable to keep all possible sources of frequency deviation quite small, and accordingly the following precautions were taken: (1) the power supply for the klystron is highly stabilized, noise and ripple in the output being together less than 1 mV; (2) the whole microwave system is mounted on a vibration-proof table; (3) the klystron is inside a Mumetal box. Half an hour after switching on, the frequency deviations without the stabilizer are less than 30 p.p.m. over ten minutes, and this is reduced to $\frac{1}{10}$ p.p.m. by the operation of the stabilizer. This system is simpler and more effective than stabilizing the klystron frequency against the microwave cavity, since to attain the same stability would require control of the cavity temperature to 0·006° C to avoid changes due to thermal expansion. In addition, measurement of the klystron frequency, which would otherwise require a separate system, is effected by measurement of the beat frequency output from the crystal diode mixer. One stage of amplification is sufficient to raise this voltage (of the order of 50 μV) to a level sufficient to operate a Marconi type TF783 wavemeter. This has an accuracy of 14 p.p.m., which in measuring a beat frequency of 10–50 Mc/s represents only $\frac{1}{20}$ p.p.m. of the microwave frequency. The latter is first determined roughly by a cavity wavemeter to identify the harmonic of 100 Mc/s being used to produce the beat frequency.

3.2 *The microwave cavity resonator.* Microwave power from the stabilized source is fed through an attenuator into a cylindrical cavity (about 4·2 cm diameter, 3·3 cm height) resonant in the H_{011} mode. The resonator is made entirely of tellurium copper since this is easy to machine, has high conductivities, and is completely free of ferromagnetic impurities; it is made in a number of sections. Power is coupled in through the lower end using two holes(6) symmetrically placed 2·2 cm apart and out through a single hole half-way up the side. The top of the cavity is formed by a close fitting cylinder projecting downwards from the top plate.

A 1·45 cm diameter central hole is bored through the top, so that the silica capsule containing the paramagnetic sample (outer diameter 1·4 cm; length 3·3 cm) can be inserted and removed without taking off the top plate. Leakage of microwave power through this hole is prevented by inserting a tube of 1·0 cm internal diameter, through which light can enter to produce atoms by photo-dissociation. The silica capsule can be replaced by a proton resonance probe (Section 2.4) which is located by a collar so that the mid-point of the proton sample is exactly at the centre of the cavity. The second proton resonance probe (the stabilizer) is similarly located in a hole 3 cm off-centre in the central block.

Inside the cavity are two vertical posts, 3·0 cm apart which are used to modulate the magnetic field at 115 kc/s (Section 3·3). Considerable care is taken to ensure that they are placed symmetrically inside the cavity, since otherwise microwave power is coupled out and the Q reduced. Their lower ends are fixed to a shorting ring which is screwed on to the base plate, and to their upper ends are fixed silver wires which pass through insulators in tubes attached to the top plate; these tubes incorporate microwave chokes.

A tuning plunger consists of a 6 mm diameter rod, which can be inserted a small distance into the cavity through an off-centre hole in the top. It is used to make small adjustments (less than 10 Mc/s) to the resonant frequency of the cavity. Provision has also been made for maintaining the resonator at a constant temperature, but so far this has not been necessary, as the large mass of the resonator ensures that temperature changes are very slow.

3.3. *Detection of paramagnetic resonance absorption.* To obtain high sensitivity it is customary to modulate the magnetic field, and to use phase-sensitive detection with a long time constant. One has also to overcome in some way the anomalous low-frequency noise of silicon–tungsten crystal detectors. This is achieved by using high-frequency modulation of the magnetic field,(7) obtained by passing a 115 kc/s current through the two posts described in Section 3.2, between which the silica capsule containing the paramagnetic sample is situated. Currents of up to 3 A r.m.s. can be passed through these posts, producing 2 G modulation in the middle; in our work, where the line width is only 0·1 G, only 0·02 G modulation is used to avoid broadening the lines. The frequency used is set by the condition that it should be as high as possible to reduce noise, but yet not much more than the line width, which for our work is often only 100 kc/s.

Whenever the microwave frequency corresponds to a frequency of resonance absorption, the power transmitted through the cavity is reduced; this reduction is modulated at 115 kc/s, and (for small sweep amplitudes) the phase and amplitude of the modulation depend on the first derivative of the absorption curve. The 115 kc/s signal from the silicon–tungsten crystal detector passes through a conventional tuned amplifier, with about 10^4 voltage gain, and then to a phase-sensitive detector, the output of which passes through a single-stage resistance-capacitance filter, forming the time constant of the detection system, and then to a d.c. amplifier (see Fig. 2). The signal is displayed as a deflexion on a panel meter, and also on a pen recorder. When searching for lines the pen recorder is used, but for measurements the central zero of the signal is located using the panel meter.

4. PERFORMANCE

4.1 *Sensitivity.* To obtain lines weak enough to make a reasonable estimate of the sensitivity, we examined the $K = 0$, $M = -1 \leftrightarrow 0$ and $0 \leftrightarrow 1$ transitions of $^{16}O^{18}O$ in a sample of molecular oxygen containing 10% of $^{16}O^{18}O$; these lines ve about $\frac{1}{20}$ of the intensity of normal molecular oxygen nes. The signal to noise ratio was 10 : 1 using a one second me constant in the detection system, and the half width sing rather less than optimum sweep amplitude) was $\frac{1}{20}$ G. he sample consisted of 4 cm^3 of molecular oxygen at a total essure of $\frac{1}{50}$ mm, i.e. 3×10^{14} molecules of $^{16}O^{18}O$. This orresponds to a value of 2×10^{-10} for χ'', the imaginary art of the total susceptibility at the peak of the line. This alue would be observed with about 4×10^{13} atoms or molecules of a gas with a partition function of 10. This sensitivity about five times that achieved using super-heterodyne etection,(8) and is roughly the same as that obtained using olometers.(9) This system, however, is free from troubles, ich as microphony, and more convenient than either of these.

4.2 *Sources of error.* The main sources of error, together ith their estimated uncertainties, are listed below.

(*a*) Setting on absorption lines: the chief uncertainty is not the location of the central zero of the derivative curve on e panel meter, but in the relationship it bears to the centre f the line. Asymmetry in the detected line shape can ntroduce a 1 p.p.m. error.

(*b*) Microwave frequency: the precision in measuring this limited mainly by its stability to about $\frac{1}{4}$ p.p.m.

(*c*) Proton resonance frequency: instability of the Clapp scillator, and the interpolation accuracy of the wavemeter ay introduce up to $\frac{3}{4}$ p.p.m. error. Also, an asymmetric roton resonance line, caused by inaccurate tuning of the ead, could account for a further 1 p.p.m.

Consistency of results; table showing the results of measurements on iodine (*see Section* 4.3)

	Mean frequency of proton resonance (*Mc/s*)	*Deviations from mean* (*p.p.m.*)								*Theory* (*see text*)
		Run 1	*Run* 2	*Run* 3	*Run* 4	*Run* 5	*Run* 6	*Run* 7	*r.m.s.*	
Line *A*	14·019 759	−1·1	+1·0	−2·2	+3·0	−0·6	—	—	1·8	−1·9
B	18·171 747	−2·0	+1·8	+0·6	+0·8	−1·4	+0·3	—	1·3	−1·6
C	19·578 592	−2·0	+3·2	−0·5	−4·4	+2·7	+1·2	—	2·7	−3·3
D	20·513 807	−0·2	+0·4	0	−2·4	+2·0	+0·2	—	1·3	+0·6
E	23·294 696	+1·2	−1·9	+5·1	−6·6	+1·9	+0·3	—	3·6	+4·4
F	26·424 492	+5·0	−0·4	−1·9	−0·8	+3·1	−3·7	−1·2	2·8	+1·5

(*d*) Determination of the average field at the sample: the wo-probe technique mentioned in Section 2.5 is open to hree sources of error:

(i) the proton resonance sample is smaller than the gas sample, so that inhomogeneity might cause the measured field to differ from the average field by up to $\frac{1}{2}$ p.p.m.;

(ii) the interpolation accuracy of the wavemeter is equivalent to $\frac{1}{2}$ p.p.m.;

(iii) the value of the field difference may change by $\frac{1}{2}$ p.p.m. in 30 min.

The tuning error mentioned in note (*c*) does not enter gain because of the much narrower proton resonance line t the centre of the field.

Thus the largest possible error in any measurement is $\frac{1}{2}$ p.p.m., and one would expect an error of 2 or 3 p.p.m. he sample used for proton resonance is a 0·163 molar olution of nickel sulphate. In this solution, the bulk iamagnetism of the water is exactly cancelled,(10) leaving nly the known internal shift.

4.3 *Consistency of results.* The consistency of the results btainable with the spectrometer is best illustrated by our easurements (to be published elsewhere in detail) on the round electronic state ($P_{3/2}$) of atomic iodine 127 (nuclear pin 5/2). A series of six precision measurements have been ade on each of six of the eighteen high field lines. The microwave frequency was always close to 9329·7 Mc/s, and for convenience all the proton resonance frequencies have been converted to correspond to 9329·700 Mc/s using the accurately known relation between the microwave and proton resonance frequencies. The results are given in the table, from which it will be seen that the r.m.s. average of the six r.m.s. deviations is 2·4 p.p.m.

A check on the results is obtained as follows. The proton resonance frequency for any one of the lines depends on the various hyperfine interaction constants, which have been very accurately determined in zero field by Jaccarino and others(11) and also on the previously unknown electronic *g*-value. So we have in effect six equations for one unknown. The deviation of the value of g_J calculated from each line from the mean value obtained from all six lines is quoted in the last column of the table. The r.m.s. average of these six deviations is 2·6 p.p.m.

ACKNOWLEDGEMENTS

The spectrometer was built at the suggestion of Dr. B. Bleaney; we gratefully acknowledge many helpful discussions with him. We also wish to thank Prof. Lord Cherwell for extending to us the facilities of the laboratory; Mr. C. D. Lustig, who helped to make the precision measurements on atomic iodine; Mr. E. J. Jenkinson, of the workshop staff, whose skill made an important contribution to the success of the work; and Mr. L. J. Arundel for helpful advice on electronics. Our thanks are also due to the Board of Admiralty for apparatus and other assistance; to Imperial Chemical Industries Ltd. for loan of apparatus; and to the Department of Scientific and Industrial Research for maintenance grants to two of us (R. A. K. and R. B. D. K.).

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A variable structure-factor graph for use in crystal-structure determination

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The instrument incorporates two tables, linked so that a rotation of one causes an identical rotation of the other. A drawing of proposed atomic positions is placed on one table and lies under a net of parallel wires which represent the contours of a structure-factor graph.(4) The spacings of these wires and the relative orientation of the drawing may be adjusted to correspond with any given point on a representation of the diffraction pattern placed on the second table. Suggestions may then be obtained, from the relative disposition of atomic positions and contour lines, for changes that would improve the agreement between the diffraction patterns of the proposed and actual structures. The instrument has already given useful assistance in a number of problems.

Although it is introduced from the standpoint of optical transforms, the instrument could equally well be used with conventional computational methods. Also, since it is virtually a one-dimensional Fourier transformer, it may find applications in other fields.

In trial-and-error methods of crystal-structure determination, the observed intensities of diffracted X-ray beams are compared with those deduced for a proposed structure; the hypothetical structure is then modified until the intensities deduced for it agree with those observed for the actual structure. The intensity of any particular diffracted beam may be regarded as a sample at a particular point (a reciprocal-lattice point) of a continuous function in reciprocal space (the Fourier transform of one unit cell of the structure). In normal computational methods, the comparison between the intensities for the two structures is made only at the sampling points; in Fourier- and optical-transform methods the observed intensities which, for practical reasons, can be obtained only at the sampling points, are compared with the continuous function for the proposed structure.(1,2) One of the advantages of using the complete transform of the proposed structure is that it is easier to see in what way the transform needs modification when the form of the function between the reciprocal-lattice points is known. In all methods, however, the real problem lies not in determining the deficiencies in reciprocal space, but in interpreting these deficiencies in terms of changes to the structure in real space. For known planar molecules the interpretation is not difficult; the only variables are rotation and translation, and techniques exist by which these parameters may be determined.(2,3) For non-planar molecules, or for molecules of unknown configuration, the interpretation is rather more complicated and the instrument to be described has been designed to assist in this operation.

Although the transform approach is used in introducing the principle, the instrument may be equally useful when computational methods are being used; this point will be amplified in the final section.

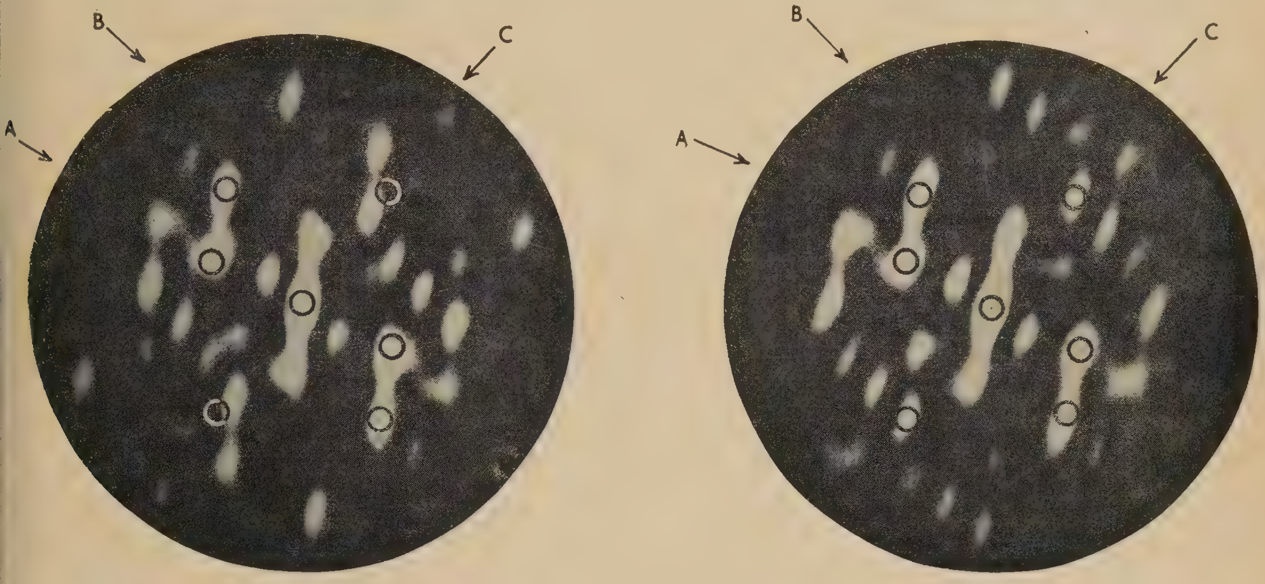
BASIC PRINCIPLE

Let us consider the problem entirely in two dimensions, using the observed intensities in the form of a weighted reciprocal-lattice section, and considering modifications to the corresponding projection of the structure as movements confined to the plane of projection; three-dimensional and stereo-chemical implications of changes in the projection are best ignored at this stage and may be used as corroboration of the evidence later on. It has been shown that, for a number of commonly occurring two-dimensional space groups, the shape and orientation of the molecule in projection may be found by considering only the strong reflexions; information about the positions in the unit cell can then be obtained from certain weak reflexions.(3) The present argument is primarily concerned with the first of these two stages. The first trial structure may give satisfactory agreement for one or two of the strong reflexions and fail for some others. A simple, hypothetical example is shown in Fig. 1(*a*). The optical transform of one molecule of a structure, of seven similar atoms, is shown with circles superimposed to indicate points of the reciprocal-lattice section at which large intensities are required; for clarity, the rest of the weighted reciprocal-lattice section has been omitted. Clearly the conditions for the points marked *A* and *B* are satisfied, but *C* lies just off the edge of a strong peak and some other neighbouring reciprocal-lattice point, lying within this peak, will have a large intensity not required by the structure. The simplest way of obtaining improved agreement would be to adjust the proposed structure so that the strong peak moves exactly on to *C*. This change should, of course, be accepted only if it leads to improved agreement in other parts of the section as well; if it does not, some other way of satisfying *C* must be sought. The instrument described may be used to predict possible structural changes such that certain parts of a diffraction pattern—for example, *A* and *B* in Fig. 1(*a*)—remain unchanged while others such as *C* are changed in some specific way.

Bragg and Lipson(4) have described the use of contoured graphs of structure factor which show the variations in the contribution made to the total amplitude at any reciprocal-lattice point as an atom is moved about in the unit cell. The use of such graphs need not be confined to reciprocal-lattice points; graphs could be drawn for any point in reciprocal space. Bragg and Lipson point out that one of the advantages of the graphs is that they show which atoms are "sensitive." That is, if an atom lies near a "plateau" where the contours are widely spaced, it can be moved about without seriously affecting its contribution; if it lies on a steep slope where the contours are close together, a small change in position may make a large change in contribution. Thus, if we had available structure-factor graphs for the points in reciprocal space under consideration (*A*, *B*, *C* and the centre of the peak near *C*, in the example of Fig. 1(*a*)] suitable atomic movements could then be chosen to avoid large changes in certain places where the agreement is already satisfactory, and to make the change required at other points.

The labour of producing such graphs would probably ake this an uneconomical procedure, but the variable graph scribed here, which can be set almost instantly to cor-spond to any point in the section of reciprocal space under nsideration, makes the technique rapid and practicable.

Since only one molecule is being considered, the graph for e two-dimensional space group $p1$ is required. (Strictly eaking, two graphs are required, one for the real part and e for the imaginary part of the structure factor if the olecule is non-centrosymmetrical. A strong peak is under nsideration, however, and a large proportion of the atoms ll consequently scatter in phase, and further, as we are t concerned at this stage with position in the unit cell, the aph can be moved, relative to the molecule, to such a sition that the imaginary part becomes negligible. This int will be discussed further in connexion with the example.)



(a)

(b)

Fig. 1. (*a*) Optical transform of hypothetical arrangement of seven similar atoms. The circles represent reciprocal-lattice points at which large intensities are required. (*b*) Optical transform of arrangement modified to satisfy the required intensity conditions. The circles are in the same positions as in Fig. 1(*a*)

e contours for the required graph are straight lines per-ndicular to the vector from the origin of reciprocal space the point considered. The amplitude represented varies usoidally in a direction perpendicular to the lines, with sitive maxima spaced a distance apart that is inversely oportional to the length of the reciprocal-lattice vector. In actice only contours representing positive and negative axima are normally needed, though it would be a simple atter to add more if it were found desirable.

CONSTRUCTION OF THE INSTRUMENT

The arrangement is shown schematically in Fig. 2. There e three main portions of the apparatus. First, there are o disks D_1 and D_2 which represent reciprocal and real ace respectively, and on which the transform and a drawing the structure are mounted; secondly, there is a set of wires, presenting contour lines, carried by a frame E, F, G, H; irdly, there are two special cursors XY and PQR, which are ed to set the spacings of the wires.

The disk D_1 rotates about a fixed point O on the baseboard. An arm OO', also pivoted at O, carries the pivot for the disk D_2 at its free end. Behind the baseboard the two disks are connected by an endless chain and two sprockets of equal diameter. They therefore rotate together and parallel directions remain parallel even when the arm OO' is moved. The movement of O' is necessary to provide relative translational movement between the graph and the structure drawing, so that the imaginary contribution to the structure factor may be minimized, as already mentioned.

The framework carrying the contour wires is a parallelogram pivoted at each corner E, F, G, H. The sides EF and GH are pivoted at J and K, which are fixed points relative to the baseboard. Rotation of EF and GH about their pivots J and K thus causes the sides FG and EH to move towards and away from each other, while remaining parallel. A set of wires fixed across the frame from EF to GH, and parallel to FG will also remain parallel to each other; their spacings will remain in a constant ratio, but the scale can be changed at will by rotation at J and K. (This device was used by Hargreaves in his structure factor machine.(5)) The framework is made of $1 \times \frac{1}{8}$ in. ($2{\cdot}5 \times 0{\cdot}3$ cm) aluminium bar and the wire is 26 s.w.g. piano wire. Some difficulty was experienced at first in maintaining the wires at a uniform tension, but this has now been overcome by fitting a small helical spring at one end of each wire. The wires pass close to the surfaces of D_1 and D_2 to minimize parallax errors.

A Perspex bridge is mounted between the disk D_1 and the wires and has a line XY scribed down its centre. This line is adjusted to be perpendicular to the contour wires. The section of the reciprocal lattice, or the transform, under consideration is mounted on D_1 with its origin coincident with O. If the point in question is now moved by rotation of D_1 to lie under XY, the wires will now be perpendicular to the vector from O to the point, as required. The drawing of the structure is mounted on D_2 in the correct orientation relative to the reciprocal figure on D_1. (For optical transforms this can be done by using the calibration streaks mentioned by Pinnock and Taylor.[(6)]) The second cursor PQR is required to adjust the scale of the graph. The lines PQ and QR, which are at right angles to each other, are scribed on a single piece of Perspex. The cursor is pivoted at Q to a second Perspex bridge across D_1 so that Q is fixed relative to the baseboard.

Suppose PQ intersects XY at M and QR intersects XY at N. It is a property of the right-angled triangle that

$$MO \times NO = OQ^2$$

or, if OQ is constant,

$$MO \propto 1/NO$$

Optical transforms are usually prepared, in this laboratory, on a scale of 5 cm : 1 Å^{-1}; structure drawings are usually prepared on a scale of 2 cm : 1 Å. For these scales, the product $ON \times MO$ for corresponding vectors should be 10 cm^2. OQ on this instrument is therefore $\sqrt{10}$ cm long. If alternative scales were to be used, it would only be necessary to provide alternative positions of the pivot Q.

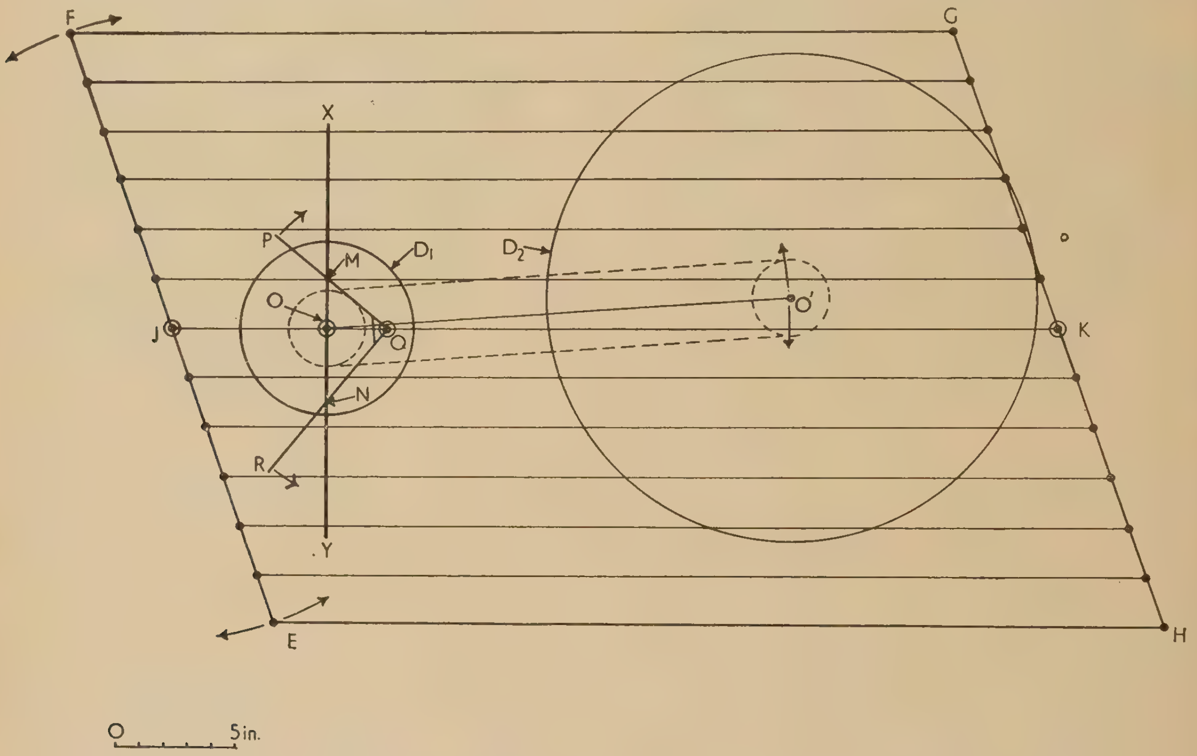


Fig. 2. Schematic diagram of the instrument

○ Pivots fixed relative to baseboard. ● Pivots movable relative to baseboard.

To set the scale of the graph for some particular point on D_1 that has already been brought under XY, PQR is rotated about Q until the intersection N lies over the point. ON is then the reciprocal-lattice vector and OM is the required spacing of the positive maxima of the graph. The middle wire JK is taken as a positive maximum and passes through O; the frame must then be adjusted so that the wire representing the next positive maximum to this passes through M. The wires are now set to represent the required graph. Movement of OO' about O may now be made, without disturbing any of the settings, to minimize the imaginary part of the structure factor as explained later. If a centrosymmetrical unit is under consideration, the wire JK must pass through the centre of symmetry. In a sinusoidal distr bution, the positive and negative maxima and the zero lin are all equally spaced, so that if zero lines are needed t fourth wire from JK is adjusted to pass over M, and eve fourth wire is taken as a positive maximum; this procedu is sometimes useful when very wide spacings are bein considered.

Full mechanical details, except for one or two speci points, have not been given as there are many possib variations in construction that could be made to suit th facilities and raw materials available.

EXAMPLE OF USE

Let us now consider the use of the instrument in derivin the transform of Fig. 1(*b*) from that of Fig. 1(*a*). Transform 1(*a*) is set up on D_1 and the corresponding drawing of the structure is placed on D_2 in the correct relative orientation; D_1 is rotated to bring A under XY, PQR is set to bring N into coincidence with A and the frame is adjusted so that the first positive maximum passes through M. The wires now represent the graph for the point A in the correct relative orientation with respect to the drawing of the structure. (In Fig. 2 the wires representing negative maxima have been omitted to make the drawing clearer.) In Fig. 3 the black dots represent the positions of the atoms from which Fig. 1(*a*) was derived and the set of lines marked "peak A" represents the positions of the wires as now set. (It is the usual practice to draw these in by running a pencil along the wires; negative maxima are represented by broken lines.) So far the adjustment of the relative position of the graph and the structure drawing has not been discussed, although in Fig. 3 the lines are drawn in the correct positions. Atoms 2, 3 and 4 lie in line parallel to the contours and, if this is chosen as a itable line for a positive maximum, atoms 5 and 7 also on maxima. The corresponding graph for the imaginary art is identical with that for the real part, but displaced a uarter of a period, so that these five atoms, at positive axima of the real part, will lie on zeros for the imaginary art; this position is therefore one in which the real part is ry much larger than the imaginary part, as is required.

The procedure is now repeated for *B*. This is the weakest f the three peaks, however, and it is not possible to reduce e imaginary contribution quite so satisfactorily; there are, fact, two equally possible settings. However, as we are ncerned only to keep this peak unchanged, if all the atomic ovements are made parallel, or nearly parallel, to the ntours for *B* there will be no change in either real or naginary part.

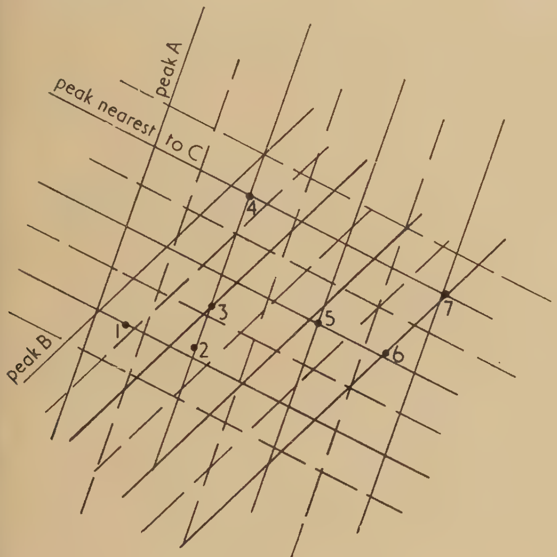


Fig. 3. Atomic arrangement used for the transform of 1(*a*), with contours for three peaks superimposed

For the centre of the peak nearest to *C* the setting is easy; toms 4 and 7 lie in line and 5 and 6 also lie in line at the ght distance away. With these lines chosen as positive naxima, 1 also lies on a maximum and 2 and 3 make only mall contributions to the imaginary part. The three sets f contours so far used are shown together on Fig. 3.

It is convenient to adjust the graph so that the wire *JK*, hich does not change position when the scale is altered, asses somewhere near the middle of the molecule; in this xample, for peak *C*, 5 and 6 would lie on *JK*. The graph is ow adjusted to correspond to the point *C*. In Fig. 4 the nes for *A* and *B*, which do not require to be changed, are eproduced and the new set of lines for *C* is shown. Atoms and 6 still lie on *JK*, corresponding to the arbitrary choice f position for the new *C* setting and it is convenient to egard these atoms as fixed. (Atoms 4 and 7 could equally ell have been used, but the movements involved are smaller the fixed atoms are somewhere near the middle of the tructure.) Atoms 1, 4 and 7 now lie close to zero contours nd therefore, being on a steep slope, are "sensitive." Atom 2 es in about the same relative position as before but is now t the other side of the maximum; the part of the graph that as moved over it is almost all "plateau" and it is not likely be sensitive. Atom 3 lies in a negative plateau region for both. Atoms 1, 4 and 7 are therefore the first choice for movement. The actual movements shown in Fig. 4 bring the atoms into a very similar position with respect to the new family of contours to that occupied at first relative to the old family. For atoms 4 and 7 the movements are parallel to "*B*" lines, as required; though not quite parallel to "*A*" lines, the movements are well within plateau regions and the imaginary part will still be small compared with the rest. For atom 1 a compromise is made; the direction of movement bisects the angle between "*A*" and "*B*" lines.

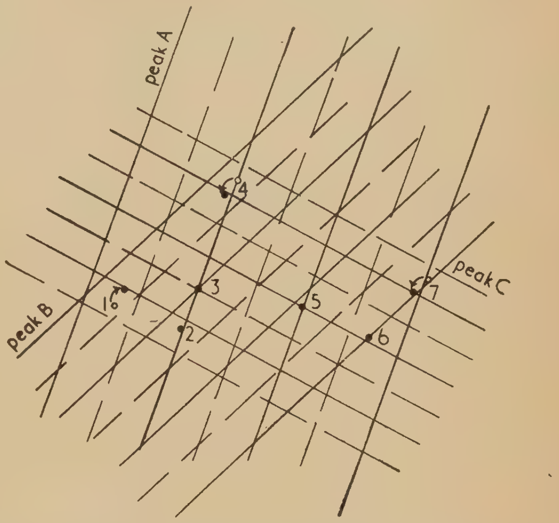


Fig. 4. Atomic arrangements used for the transform of 1(*b*), with contours for points *A*, *B* and *C* superimposed. The original positions of atoms that have been moved are indicated by open circles

■ Final positions.
○ Original positions of atoms that have been moved.

Fig. 1(*b*) is the transform derived in this way and, as can clearly be seen, the problem set has been solved; *A* and *B* are practically unchanged and the peak near to *C* has moved exactly on to it. The solution is not, of course, unique, and the proposed changes would only be accepted, as has already been stressed, if they lead to improvements in other regions of the reciprocal-lattice section.

DISCUSSION

It must be emphasized that this is not a device which can be used purely objectively to give a unique answer; it is primarily an aid in thinking about problems and its main use is as a source of ideas for possible changes. Continual recourse must be made to the test of overall agreement between observed and deduced intensities. The apparatus has been in use for a little over a year and has given considerable help in a number of problems. McConnell(7) used it in his investigation of hydrogen positions for diphenylene naphthacene. Pinnock(8) used it in the re-investigation of the structure of triphenylene, and it is at present being used in a number of problems as yet unpublished.

One feature that perhaps deserves mention is that the use of this technique permits a worker using conventional computational methods, who perhaps has no access to an optical diffractometer and who is not prepared to calculate complete transforms, to gain some of the advantages of transform techniques. For example, in the problem used above as an illustration, the first test of the proposed structure would be to calculate the contribution of one molecule—not of the complete unit cell—at *A*, *B* and *C* where strong intensities are observed. Intensities at *A* and *B* would be found satisfactory but *C* would be far too weak. The contribution to a few reciprocal-lattice points adjacent to *C* could then be calculated and, when a strong one was found (corresponding, of course, to the peak of the transform near to *C*) the present technique could be applied to move it on to *C*.

In addition to the uses already outlined the instrument may have other potentialities. It is, after all, merely a rapid means of transforming real to reciprocal space, and this is the fundamental operation underlying all diffraction effects, not only for X-rays, but also for other electromagnetic radiations.

ACKNOWLEDGEMENTS

We wish to acknowledge our indebtedness to Mr. W. Hughes who made the instrument and made considerable contributions to the mechanical design, to Prof. H. Lipson for helpful discussions and advice, and to Mr. J. F. McConnel and Dr. P. R. Pinnock who have used the instrument an offered helpful criticisms.

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A thermistor device as automatic gain control in lamp-photocell transducer systems

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This paper describes the design of a regulator using thermistors to compensate for the slow drift of illumination from a lamp source and changes in photocell characteristics which normally affect the calibration accuracy of vibration equipment when a photoelectric transducer is employed. The regulator operates by stabilizing the mean component of the modulated voltage across the photocell load resistance itself, comprising one or more series-connected thermistors of the indirectly heated type. Design details are given of a regulator which stabilizes the system to within 0·03% when the light beam is symmetrically modulated by the vibration under study.

In the investigation of mechanical vibrations a photocell is occasionally used as a transducer between a modulated light beam and the measuring and display apparatus, more especially in vibrating systems in which it is inconvenient or impossible to use any other method. The permanence of calibration then depends on the absence of change in illumination and in the photocell characteristics.

Although the light source may be supplied from a highly stabilized voltage and carefully aged before calibration of the equipment is carried out, there is always a downward drift of illumination intensity: a large short-term change after switching on, followed by a long-term drift due to deterioration of the lamp and blackening of the glass envelope.

The change in photocell characteristics is small if the cell is carefully used. Nevertheless, a change does occur which may be minimized by the use of a precision photometric type of cell such as the KMV 6. It is found, however, that the illumination drift is responsible for most of the trouble, and in equipment which cannot be frequently recalibrated without inconvenience, this leads to progressively greater inaccuracy of absolute measurement.

During the investigation of shaft vibrations in the neighbourhood of a critical speed by a photoelectric method, calibration drift was such that the accuracy of the equipment could not be relied upon to more than 5% at any time: and during a short run it was usually worse than this. The mechanical arrangement of the apparatus made frequent calibration inconvenient, particularly during a long experiment in which constant operating conditions were required and disturbance of bearings and other components undesirable.

It is possible to design a regulator operating on the lamp supply to annul changes in the illumination and photocell, but such an arrangement is not generally applicable since it depends on the particular circuit of the lamp voltage stabilizer. This method is also undesirable on account of the danger of lamp over-voltage if for any reason the regulator becomes unstable, and adequate protection is required in the lamp circuit.

A regulator(1) has been developed which simultaneously compensates for changes in the light source and in the photocell without modification of the lamp supply, and although depending on the properties of thermistors, is self-compensating for ambient temperature changes and drift in the associated valves and components.

PRINCIPLE OF OPERATION

The action of the regulator depends on the properties of series-connected thermistors(2, 3) which are used in place of the normal fixed resistor as the photocell load.

When a vacuum photocell having a sensibly linear response is exposed to a modulated light, the a.c. and d.c. components of the signal obtained are both proportional to the product of the light intensity and the cell sensitivity. If, therefore, it is required to immunize the a.c. component from unavoidable changes in these two factors, any system which similarly nmunizes the d.c. component will clearly do so. An example f such a system is an arrangement whereby the resistance alue of the photocell load resistor is automatically varied so s to keep the steady voltage component developed across it t a fixed level.

The photocell load resistor comprises six indirectly-heated hermistors having both resistance elements and heaters eries-connected.

The mean component of voltage developed across the hotocell load is compared with a reference voltage, the error eing amplified and used to control the current in the hermistor heaters. The steady-state error may thus be educed to a very low value depending on the overall gain of he feedback loop.

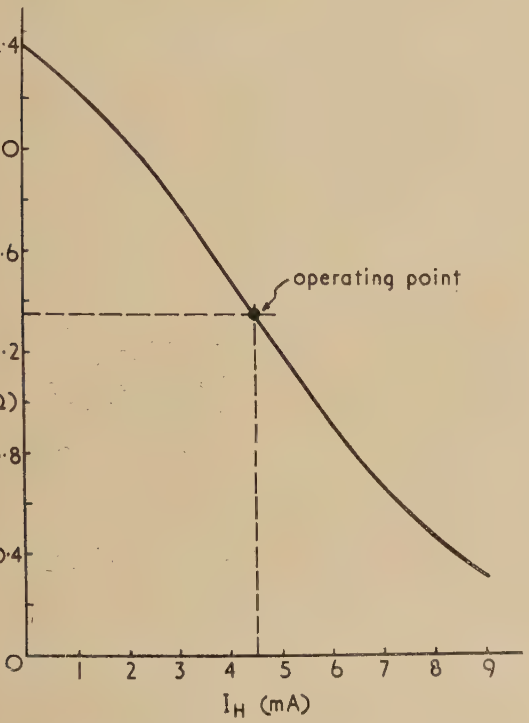


Fig. 1. Characteristics of four type B5513/60 and two type B2552/60 thermistors connected in series

The highest value of thermistor commercially obtainable at he moment is 0·5 MΩ, so that any reasonable value of load esistance may be obtained by series connexion. In this pplication four type B5513/60 and two type B2552/60 are sed, the former having a resistance of 0·5 MΩ at 20° C vith zero heater current and the latter 0·25 MΩ under the ame conditions.

Fig. 1 shows the combined characteristic of the six hermistors. It may be seen that there is an almost linear art centred on 4·5 mA heater current and that the lope of the characteristic in this region is approximately × 10^5 Ω/mA. Any combination of thermistors may be sed according to the load resistance and sensitivity required, lthough wide departures from the values specified in this pplication may require some adjustment of amplifier gain nd/or stabilizing network time-constants, as will be shown ater. It is important that the regulator itself should not ntroduce spurious errors owing to drift in valves, and for his reason the use of a thermionic device such as a differential mplifier or cathode-follower as error-detector cannot be tolerated. A Carpenter high-speed relay is employed for this purpose.

In Fig. 2 the a.c. component of the voltage developed across R_t is highly attenuated by the 10-section filter network, $R_3C_1, \ldots,$ etc., and the mean component is applied to contact 1 of the high-speed relay, S_1, contact 2 being connected to the reference voltage. This is shown as adjustable by potentiometer P_1 and derived from the stabilized h.t. supply. Any other arrangement may be used. R_5C_2 is intended to absorb small surges and may not be required. The small capacitance C_{13} suppresses noise which may develop at the relay contacts. S_1 operates at 50 c/s, the error voltage between contacts 1 and 2 being converted to a rectangular wave of appropriate magnitude and phase. The first stage of the amplifier employs a low-noise pentode (type EF37A) and has a gain of 44 dB. The second stage uses a 6F12 pentode and the gain is 38 dB. The total gain is thus 82 dB, approximately 12 600 times.

The second high-speed relay S_2, synchronized with S_1, rectifies the magnified error voltage in conjunction with the amplifier output network C_9R_{14}. The relay contacts must be arranged so that if the voltage at contact 1 of S_1 exceeds the reference value, C_{10} is positively charged through R_{15}, while if the reference exceeds the mean cell voltage, C_{10} is charged negatively.

The cathode-follower V_3 isolates the smoothing network $R_{15}C_{10}$ from the stabilizing network which follows it, $C_{11}R_{17}R_{18}C_{12}$ in conjunction with V_4. The stabilizing network is a conventional combination of phase-advance and quasi-integration networks, the "Miller effect" of V_4 being used to simulate $(m + 1)C_{12}$ between the lower end of R_{18} and earth owing to the long time-constant required and the inconveniently large capacitor which would otherwise be necessary in this position. The insulation resistance of this capacitor must be very high if full zero-frequency gain is to be realized.

The cathode-follower V_5 is unnecessary in the circuit shown. V_3 and V_5, however, constitute a double triode and V_5 is inserted to provide for the isolation of an additional network should this ever be required. The cathodes of V_3 and V_5 are returned to a negative supply in order to force approximately 5 mA through the valves and maintain a high value of mutual conductance and to avoid the possibility of cut-off should C_{10} develop a large negative voltage. The 250 V negative supply was available, but this is unnecessarily high and could be much reduced with proportional reduction of R_{16} and R_{22}.

The heater-current controller, comprising V_6 and V_7, is a cathode-follower used as a voltage-current converter. The heater winding H consists of six 100 Ω windings in series and R_{23} is necessary to preset the mean current to the mid-point of the linear region of the characteristic of Fig. 1. The 0–10 milliammeter M is a useful indicator of correct regulator operation. The switch K is closed when setting the operating point and opened to bring the regulator into operation. V_6 and V_7 are shown as triode-connected pentodes since these were used in an early attempt to obtain a higher value of conversion factor by means of a differential arrangement. A parallel-connected double triode is satisfactory in this position.

The high-speed relays S_1 and S_2 are Carpenter-type relays 3PG22 and 3E2 respectively. In the former the armature contact is directly brought out by a flexible connexion instead of passing through the armature body and the operating coil is screened, minimizing a.c. hum pick-up in the amplifier. These relays might with advantage be replaced by the miniature type 5PX.

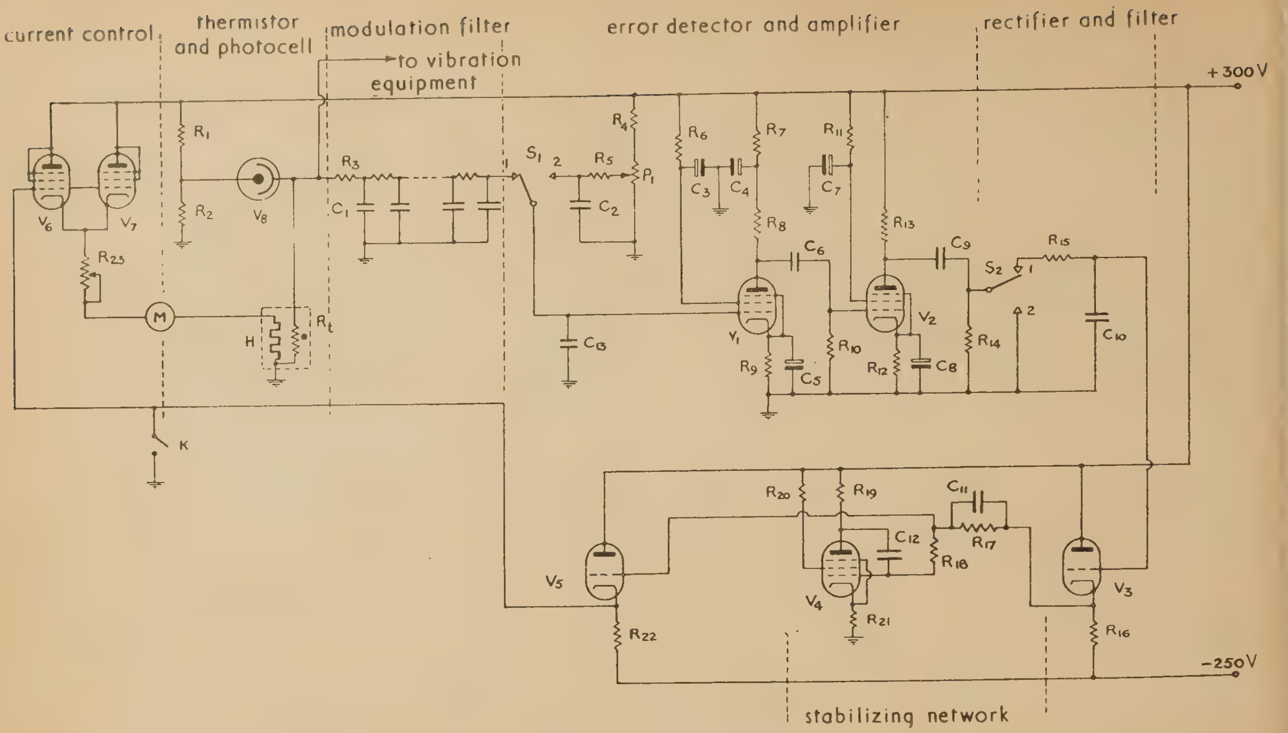


Fig. 2. Circuit diagram of regulator

R_1 = 270 kΩ
R_2 = 100 kΩ
R_3 = 0·25 MΩ (10 required)
R_4 = 0·5 MΩ
R_5 = 470 kΩ
R_6 = 1 MΩ
R_7 = 22 kΩ
R_8 = 220 kΩ
R_9 = 3·3 kΩ
R_{10} = 1 MΩ
R_{11} = 20 kΩ
R_{12} = 150 Ω
R_{13} = 15 kΩ
R_{14} = 1 MΩ
R_{15} = 10 MΩ
R_{16} = 50 kΩ (2 W)
R_{17} = 3·3 MΩ
R_{18} = 168 kΩ
R_{19} = 15 kΩ
R_{20} = 20 kΩ
R_{21} = 150 Ω
R_{22} = 50 kΩ (2 W)
R_{23} = 1 kΩ
R_t = six type B5513/60 and two type B2552/60 thermistors connected in series.
P_1 = 5 kΩ
C_1 = 0·2–0·4 μF (10 required)
C_2 = 1 μF
C_3, C_4 = 16 μF (electrolytic, 350 V wkg.)
C_5 = 200 μF (electrolytic, 6 V wkg.)
C_6 = 0·1 μF
C_7 = 16 μF (electrolytic, 350 V wkg.)
C_8 = 600 μF (electrolytic, 6 V wkg.)
C_9 = 0·1 μF
C_{10} = 2 μF
C_{11} = 1 μF
C_{12} = 8–10 μF (depending on stage gain of V_4)
C_{13} = 0·001 μF
V_1 = EF37A
V_2, V_4 = 6F12
V_3, V_5 = 12AT7 (half)
V_6, V_7 = EF42
V_8 = photocell, type 20CV
S_1 = Carpenter high-speed relay type 3PG22 (T.M.C.)
S_2 = Carpenter high-speed relay type 3E2 (T.M.C.)

CALCULATION OF PERFORMANCE

The performance of the regulator is governed by the overall gain of the feedback loop and by the nature of the lagging time-constants inherent in the thermistor and filter networks, the response depending on the proportioning of the stabilizing network constants so that a reasonable stability margin is maintained. Since the regulator is intended to compensate for very slow drift of illumination and photocell characteristics, a slightly oscillatory response to a step-function change may be tolerated.

The following constants are defined:

K_t = change of thermistor resistance for 1 mA change of heater current, estimated from Fig. 1 = 3×10^5 Ω/mA
K_c = change of voltage across thermistor for 1 Ω change of thermistor resistance, estimated from load line on photocell characteristics = 1×10^{-6} V/Ω
A_1 = amplifier gain = 12 600
A_2 = cathode-follower gain = 0·95
G = voltage-current conversion factor of heater current control = 0·9 mA/V
$T_1 = R_3C_1$ = 0·05–0·1, the response being more oscillatory but still acceptable with the higher value
$T_2 = 2R_{15}C_{10}$ = 80, the smoothing filter time-constant, the factor 2 being necessary owing to the nature of the applied waveform
$T_3 = C_{11}R_{17}$ = 3·3
$T_4 = (m + 1)C_{12}R_{18}$ = 71·5, with m = 50 and C_{12} = 8·5 μF
T_5 = thermal time-constant of thermistor. This has been averaged at 4 s, although the time-constant is slightly longer for cooling than for heating in a high vacuum type
$M = R_{17}/R_{18}$

Let $f_1(p), \ldots, f_4(p)$ be the transfer functions of the 10-section filter $R_3C_1, \ldots$, etc., the smoothing filter $C_{10}R_{15}$, the stabilizing network and the thermistor. Then we have

$$f_2(p) = 1/(1 + pT_2);$$

$$f_3(p) = \frac{(1 + pT_3)(1 + pT_4)}{(1 + pT_3)(1 + pT_4) + MpT_4};$$

$$f_4(p) = K_t/(1 + pT_5)$$

If v_0, v_f and v_r are respectively the voltage across the thermistor (i.e. the desired output voltage which is to be applied to external apparatus), the filtered mean component at contact 1 of relay S_1, and the reference voltage, we have the following relations:

$$v_r - v_f = e \text{ (error voltage)} \tag{1}$$

$$v_f = v_0 \,.\, f_1(p) \tag{2}$$

$$\begin{aligned} v_0 &= A_1A_2^2GK_tK_c \,.\, f_2(p) \,.\, f_3(p) \,.\, f_4(p) \,.\, (v_r - v_f) \\ &= K \,.\, f_2(p) \,.\, f_3(p) \,.\, f_4(p) \,.\, (v_r - v_f) \end{aligned} \tag{3}$$

vhere $K = A_1 A_2^2 G K_t K_c = 3050$, the value 3000 being taken as a round figure.

$$v_0/v_r = \frac{K \,.\, f_2(p) \,.\, f_3(p) \,.\, f_4(p)}{1 + K \,.\, f_1(p) \,.\, f_2(p) \,.\, f_3(p) \,.\, f_4(p)} \qquad (4)$$

The loop gain is $K \,.\, f_1(p) \,.\, f_2(p) \,.\, f_3(p) \,.\, f_4(p)$, and the steady-tate error $v_r/(1+K)$ if the error is taken as the difference etween v_f and v_r, which in the steady state is the same as hat between v_0 and v_r.

The response of the system could be found to any form of nput from equation (4), but this is of less immediate nportance then the determination of stability from the pen-loop gain. This may be carried out by Bode's decibel –log frequency analysis,(4) using straight line approximations o the factors of the individual transfer functions. The omplete Bode diagram is shown in Fig. 3 with the exception f the 10-section filter characteristic, the individual response haracteristics, $f_2(j\omega)$, . . . , etc., also being indicated.

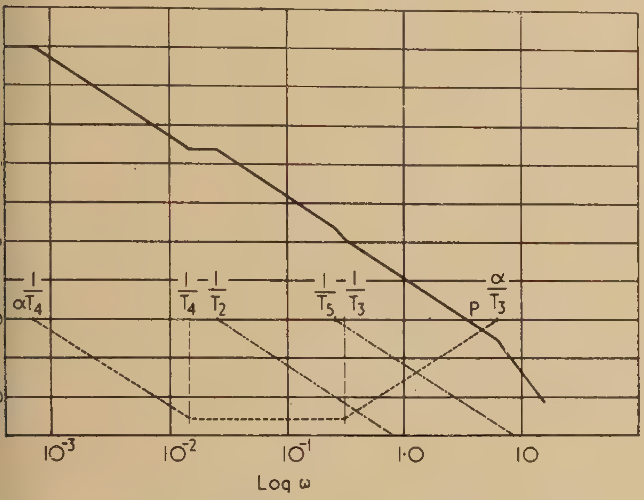


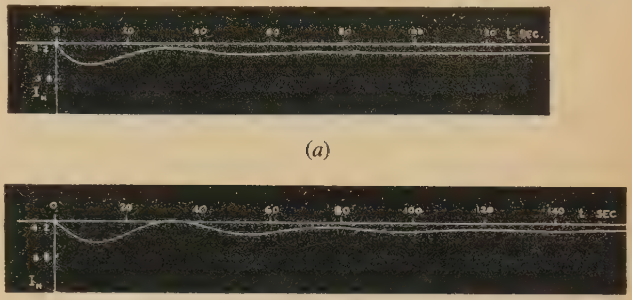
Fig. 3. Decibel log frequency characteristic of regulator (10-section filter characteristic omitted)

The frequency response function of the 10-section filter as not been accurately determined. If each section were solated, then $f_1(p) = 1/(1 + pT_1)^{10}$, and on the Bode diagram his would be represented by a cut-off slope of 60 dB/octave vith a phase-shift of 450° at the break point, $\omega = 1/R_3C_1$.

If modulation components down to a frequency of 10 c/s re to be effectively suppressed, either a simple 2- or 3-section ilter of very large time-constant must be used or a multi-ection filter of much shorter time-constant. In the former ase, it may easily be seen that a negative slope of 12 dB/octave r more, occurring anywhere to the left of point P (Fig. 3) vould result in instability, whereas if the multi-section filter s adopted, the region of rapid attenuation and excessive hase-shift can be confined to a less dangerous region on the ight where the gain is less than unity. Were the simpler ilter used, it would be necessary to decrease the overall gain nd alter the time-constants in such a manner that the haracteristic crossed the zero-gain axis at a rate not greatly xceeding 6 dB/octave. If the lower modulation frequency imit is raised, the filter problem is less acute and the stability nargin increased.

The steady-state error in this application is 0·03%, if the oop gain is taken as 3000, while Fig. 3 shows that the lecibel–log frequency characteristic crosses the zero-gain xis at a negative slope of 6 dB/octave in the absence of the 10-section filter, indicating that the system in this condition is stable.

As mentioned above, the exact calculation of $f_1(j\omega)$ has not been undertaken. The result is an expression of the tenth degree in ω, giving a steep cut-off in the neighbourhood of $\omega = 10$ or 20, depending on $T_1 = 0{\cdot}1$ or $0{\cdot}05$. The higher value of T_1 gives an acceptable response, but values much greater than this lead to excessive settling time and ultimately to instability. Fig. 4 shows the response of the system (thermistor heater current) to a small step change of light intensity, (a) using the 10-section filter with $T_1 = 0{\cdot}05$, and (b) with $T_1 = 0{\cdot}1$. This type of change would not occur in practice with a highly stabilized lamp supply and serves to illustrate the decrease of stability margin as T_1 is increased.



(a)

(b)

Fig. 4. (a) Response of thermistor heater current to small step decrease in light intensity $T_1 = 0{\cdot}05$. (b) As in (a) but with $T_1 = 0{\cdot}1$

The thermistor heater current is controlled by V_6 and V_7 in parallel. In a triode-connected cathode-follower the current is closely given by

$$I = \frac{g_m}{1 + g_m R_c}(V_g + V_{ht}/\mu)$$

in which g_m and μ are the mutual conductance and amplification factor, R_c the load resistance, and V_g and V_{ht} the grid input and anode supply voltage.

The value of I at $V_g = 0$ is to be about 4·5 mA, i.e. 2·25 mA in either valve. In a triode-connected EF42 pentode, $\mu \simeq 60$, while g_m is estimated at 5 mA/V when $I = 2{\cdot}25$ mA. With $V_{ht} = 300$ we obtain $R_c = 1{\cdot}01$ kΩ.

The cathode load resistance comprises R_{23} in series with six thermistor heater windings each of 100 Ω resistance, so that $R_{23} = 1$ kΩ will afford a sufficiently wide range of variation of the operating point.

It may be seen that if R_c is in the region of 1 kΩ, the multiplier $g_m/(1 + g_m R_c)$ is slightly less than unity and the exact value of g_m of little significance. For example, if g_m is over-estimated at 10 mA/V, $R_c = 1{\cdot}06$ kΩ.

SOURCES OF ERROR

Stabilization of the mean voltage across the thermistor presupposes that the modulation of the light beam is symmetrical and that no d.c. component exists by virtue of the modulation waveform itself. If such a d.c. component is present owing to asymmetry of the vibration under study, stabilization occurs at a new mean level, since the regulator always acts to bring the net mean level into equality with the reference. There will thus be a positive or negative error according to the direction of the asymmetry.

The regulator by its nature is unsuitable for very slow vibrations since the modulation filter is then useless. A modified system overcoming this disability has been designed but is not described in this paper.

The use of linear theory in the analysis appears to be justified over the small operating range occurring in practice. If the regulator is brought in when a very large error exists, the action will be highly non-linear at first owing to the excessive error between the thermistor voltage and the reference. The settling time under these conditions will be longer.

The regulator is self-compensating for ambient temperature changes provided the extremes are insufficiently wide to drive the operating point too far up or down the characteristic of Fig. 1. A very high ambient temperature which is continuously maintained may be offset by lowering the reference voltage. In normal operation a slight increase of ambient temperature results in a decrease of thermistor heater current and *vice versa*. If this decrease is excessive, lowering the reference voltage causes regulation at a lower thermistor voltage, demanding a lower value of thermistor resistance. The heater current then increases automatically and the operating point may be returned to the optimum position. This expedient is fortunately not required for the normal limits of laboratory temperature, for, if adopted, it would entail recalibration of the vibration equipment associated with the photocell. Drift in valves is also compensated for, while variation of amplifier gain merely results in a small change of steady state error. This might be reduced, if necessary, by using an amplifier having a higher intrinsic gain with overall negative feedback; but such elaboration has not so far been justified.

CONCLUSIONS

A regulator has been described which may be applied t any lamp-photocell combination used in vibration measurement where the lowest frequency is about 10 c/s. With som modification to the modulation filter and other time-constant the lower frequency limit could be further reduced.

This type of regulator is advantageous in that correction i applied for both illumination drift and changes in the photocell characteristics. Interference with the lamp supply i obviated and auxiliary optical devices, such as are required for certain regulators operating on the light beam itself, are unnecessary. The regulator reduces the calibration error in apparatus connected to the photocell to about 0·03% provided the vibrations under study modulate the light beam symmetrically. If asymmetric modulation occurs, the error increases in proportion to the mean component of the modulating waveform. In most instances this asymmetry is absent or very small.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance given by Mr. D. J. Simpson in making some of the thermistor measurements and by Mr. G. A. Davidson and Mr. W. McKenzie in the construction of the regulator.

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A small vacuum induction furnace

By J. C. Matthews, B.Sc., Ph.D.,* Physics Department, University of Leeds

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Melts on a laboratory scale, up to 300 g, may be made under high vacuum. Material may be added to the crucible from a hopper and the melt cast into a split copper mould while under high vacuum. The furnace is used in conjunction with a high-voltage, high-frequency generator, and although intense ionization occurs this does not affect the functioning of the furnace.

A small vacuum induction furnace capable of handling melts up to 300 g has been constructed for the preparation of high melting-point alloys, and in particular for those of the iron–chromium system.

The design is based on that of the larger version described by Winklers(1) and built by Geraetebau–Anstalt Balzers, which uses a stainless steel vacuum tank of approximately 30 in. diameter, power being supplied from a rotary generator at less than 300 V in order to avoid ionization. The present furnace was designed to be used in conjunction with an available Radyne oscillator generator (by Radio Heaters Ltd.) operating at 500 kc/s and having an output of 10 kW at 1500 V.

The size of the furnace was dictated by the availability of material for the vacuum jacket which, for economy in time and cost, has been constructed of mild steel tube, having a wall thickness of $\frac{3}{16}$ in., rather than the more usual stainless steel. It has been found that this does not significantly reduce the power to the contents of the crucible nor does the jacket become unduly warm when the empty coil is excited.

The jacket is 11 in. long, has an outside diameter of 6·25 in. and is flanged at its top and base. The base flange fits directly on to the oil baffle of a type 403 diffusion pump (by Edwards High Vacuum Ltd.). The top flange is of the same diameter, and carries two pegs which locate in a corresponding pair of holes in the flat lid which is sealed by a trapped O-ring, no bolts or clips being used to hold it down. This enables the lid to be removed most easily for charging and cleaning, and at such times the lid stands on three short legs, thus avoiding soiling the O-ring seal.

DETAILS OF FURNACE

Coil-crucible assembly. In the preparation of homogeneous alloys it is necessary to chill-cast the specimen directly from the melt in order to avoid segregation. In this urnace (see figure) the specimens are chill-cast by lip-pouring nto a copper mould.

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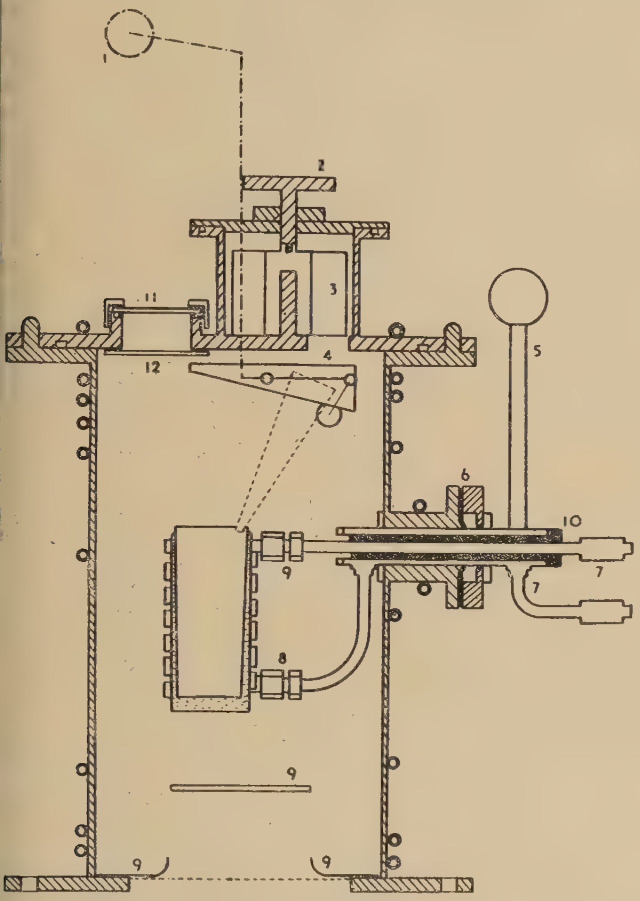
* Now at Physics Department, University of Nottingham.

To achieve this the coaxial leads to the work coil enter the acuum space through a rotary Wilson seal, interchangeable oils being attached to these by ¼ in. petrol unions which ave been found to be quite suitable for high vacuum operaion. The outer conductor at earth potential consists of two oaxial copper tubes, having sealed ends, which carry the ooling water in the anular space between them. The inner onductor is a ¼ in. tube supported by Araldite, the outer end of the insulation space being sealed by wax. These coaxial leads are connected to the radio-frequency generator by several 9 in. lengths of heavy copper wire inside rubber pressure tubing.



Vacuum induction furnace

(1), chute operating lever; (2), hopper rotating knob; (3), six-sector hopper; (4), chute; (5), coil-crucible rotating handle; (6), Wilson rotary seal; (7), coaxial water-cooled leads; (8), unions to interchangeable work coils; (9), metal splash traps; (10), Araldite insulation to central lead; (11), Pyrex observation window; (12), shutter plate.

The internal diameter of the coil is made approximately 4 mm greater than the crucible in order to accommodate a 2 mm layer of alumina cement on the crucible which, after being baked at 1500° C, gives some protection against racture.

The lid. In melting iron and chromium to form alloys it as been found necessary to add the chromium in small uantities to the bath of molten iron, since otherwise the hromium forms an arch over the molten iron and cannot e melted. This is confirmed by the work of G. Pomey⁽²⁾ who found precisely the same effect. In the present furnace chromium pellets are held in six sectors of a hopper which is rotated through a vacuum seal and a simple clutch. As the hopper is rotated the contents of the corresponding sector fall through a slot in the flat lid into a chute which may be tipped by an external lever to deposit the pellets into the crucible. The lid of the hopper is held down by the vacuum only, the seal being made by a trapped O-ring.

An observation window of Pyrex glass is included in the lid and sealed by an O-ring; if necessary, the window may be shielded during operation by an externally operated shutter. During a melt it is found that heavy deposition of metal occurs when the vapour pressure of the metal rises above 10^{-3} mm of mercury and at such times the shutter is closed.

Mould. The present furnace uses a split cylindrical copper mould, not shown in the figure, mounted on a vertical rod and may be easily adjusted to any position in the vacuum space behind the coil-crucible assembly. The diffusion pump and baffle are protected against metal splash by a trap and copper gauze.

The pumping system includes a type 403 diffusion pump (by Edwards High Vacuum Ltd.) and a type 1S150 rotary pump, the pressure being indicated by a calibrated Pirani gauge (by General Electric Co., Ltd.).

MELTING PROCEDURE

In preparing iron–chromium specimens the required amount of iron is placed in the crucible, while the chromium is divided between the six sectors of the hopper. Since one of the sectors is already above the slot the corresponding portion passes directly into the chute. The vacuum space is pumped down to less than 10^{-4} mm of mercury in three minutes, at which point the radio-frequency power is switched on, at first at low power in order to avoid submitting the crucible to too great a thermal shock. The power is gradually increased until the iron melts after approximately ten minutes. The first addition of chromium is now made with the window shutter closed, whereupon there is an immediate vigorous degassing, the pressure rising to several millimetres of mercury. When the degassing is complete and the pressure has been reduced below 10^{-4} mm of mercury, a further addition of chromium is made by rotating the hopper through 60° and operating the chute lever. (The melt may be observed through the window only when the pressure has fallen below 10^{-4} mm of mercury.) When all the chromium has been added the power is increased until the vapour pressure of the melt rises above 10^{-3} mm of mercury, when the coil is turned by the lever attached to the rotary leads and the specimen is cast in the copper mould.

The radio-frequency generator used with this furnace operates at a high potential and, during the melting process, an intense ionization occurs in the vacuum space. Since the generator is capable of supplying the additional power no steps have been taken to reduce this ionization.

ACKNOWLEDGEMENTS

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An improved inductance method for measuring susceptibilities of small paramagnetic specimens at low temperatures

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An apparatus is described with which the susceptibilities of small paramagnetic specimens can be determined at temperatures between 77 and 1·8° K. The measurements are made in terms of the change of mutual inductance produced by moving a specimen inside a coil system, using a Hartshorn bridge operating at 175 c/s to measure the inductance. The chief advantage of this type of apparatus is its simplicity of operation, since it involves no delicate moving parts. The sensitivity and reproducibility of the apparatus were investigated using a specimen of manganous ammonium sulphate and it was found that susceptibilities of the order of 3×10^{-6} c.g.s. units could be measured to an accuracy of 1%. Sources of error are discussed.

Although mutual inductance methods of measuring paramagnetic susceptibilities have long been used at temperatures in the liquid helium range and below,$^{(1)}$ they have found little favour with workers making measurements at higher temperatures. There are two main reasons for this. In the conventional experimental arrangement$^{(2)}$ the specimen is rigidly located at the centre of a pair of coils, the mutual inductance of which is measured with either a ballistic galvanometer or an a.c. bridge. When the temperature of the specimen is changed the inductance varies by an amount proportional to the change of susceptibility, the constant of proportionality depending on the dimensions of the coils. Since the inductance of the empty coil changes somewhat from experiment to experiment, it is only possible to measure *variations* of susceptibility with temperature, but not absolute values which include temperature independent contributions. At very low temperatures such contributions are often unimportant, but at higher temperatures an absolute measurement is generally required. The second limitation also arises, indirectly, from the same considerations. The mutual inductance measured is the sum of two parts: M_1 due to the specimen and M_0 due to the empty coil. For a small specimen M_1 may be some 10^4–10^6 times smaller than M_0 so that a very small instability in M_0 can completely mask the variation of M_1 with temperature. Though the changes in M_0 can be reduced to a certain extent by careful construction of the coil, they still limit the useful sensitivity of the conventional arrangement to about 10^{-4} c.g.s. units. For the measurement of small or magnetically "weak" specimens, at temperatures in the liquid hydrogen and nitrogen ranges, a sensitivity some hundred times greater is necessary.

Both these limitations disappear if we can move the specimen during the course of the experiment. If we measure the change of inductance when the specimen is removed from the coil we obtain a direct measure of the total susceptibility at that temperature, including temperature independent contributions. Any instability in M_0 will affect the measured change of inductance only in so far as the variation occurs during the rebalancing of the a.c. bridge, an operation which takes a few seconds. Furthermore, since the fluctuations in M_0 are found to be largely random, their effect can be completely eliminated by repeating the pair of readings several times.

In this paper we describe an apparatus, built on the above principle, designed to measure the susceptibility of small specimens (maximum diameter 5 mm) at temperatures in the liquid nitrogen, hydrogen and helium ranges. The advantage of restricting the size of the specimen was that a small diameter measuring coil could then be used, such a coil having a high sensitivity for a given number of turns. Since the measurements were quite independent of changes in M_0 it was not necessary to keep the coil at a fixed temperature, and it was possible, therefore, to immerse it directly in the refrigerant controlling the temperature of the specimen. The inner diameter could then be reduced to a value just greater than that of the specimen. The mutual inductance was measured with the usual type of a.c. Hartshorn bridge. It must be emphasized that, with an a.c. method, moving the specimen does not produce any kind of ballistic effect, the measurement consisting of two static readings on an inductance bridge, which, however, are made in quick succession to eliminate the effect of slow, spurious changes in M_0.

THE EXPERIMENTAL ARRANGEMENT

(*a*) *The cryostat.* A simplified diagram of the experimental arrangement is shown in Fig. 1. The specimen was enclosed in a thin polytetrafluorethylene (Teflon) container which was screwed on to the end of a long Tufnol rod, 3 mm in diameter. At its upper end the rod was attached through a flexible coupling to a grooved brass drum, which could be turned from the outside by means of a shaft passing through an O-ring seal. The limits of movement of the specimen were controlled by adjustable stops fixed to the outside of the drum casing. The flexible coupling was made from a piece of spring curtain rod. This gave a positive movement, reproducible to better than 0·5 mm. The drum casing was attached to the lower part of the apparatus by means of a greased ground joint, enabling the specimen to be changed without any further dismantling. The specimen and rod were enclosed in a tube containing a small pressure of helium gas to ensure thermal equilibrium. The lower end of the tube was made of Pyrex glass to reduce the effect of eddy currents from the measuring coil.

The measuring coil was wound on a Carp brand Tufnol former which fitted closely round the glass tube. The secondary was wound in two identical halves which were connected in opposition in order to reduce M_0 to a conveniently small value. Each half consisted of 25000 turns of 46 s.w.g. enamelled, rayon-covered copper wire. The primary consisted of eight layers of 38 s.w.g. enamelled, rayon-covered copper wire, wound on top of the two secondaries. The current in the primary was usually of the order of 0·1 A, corresponding to a field at the specimen of 40 G. Throughout the winding operation Tufnol cement was applied to the coil, and after careful drying out this was baked for twenty-four hours to ensure maximum mechanical rigidity. When the coil had been completed it was found that, although the two halves of the secondary had been made as alike as possible, the residual inductance M_0 was still about 2 mH.

This was not very surprising since the uncompensated nductance of either half of the coil was about 100 mH. In order to reduce M_0, turns were removed from one end of the primary until a convenient value of M_0, of the order of 200 μH, was obtained. Winding the secondary in two compensating halves has the further advantage of doubling the effective sensitivity of the coil, since the change of inductance produced by moving the specimen from one-half of the secondary to the other is just twice that obtained by withdrawing it completely from the coil.

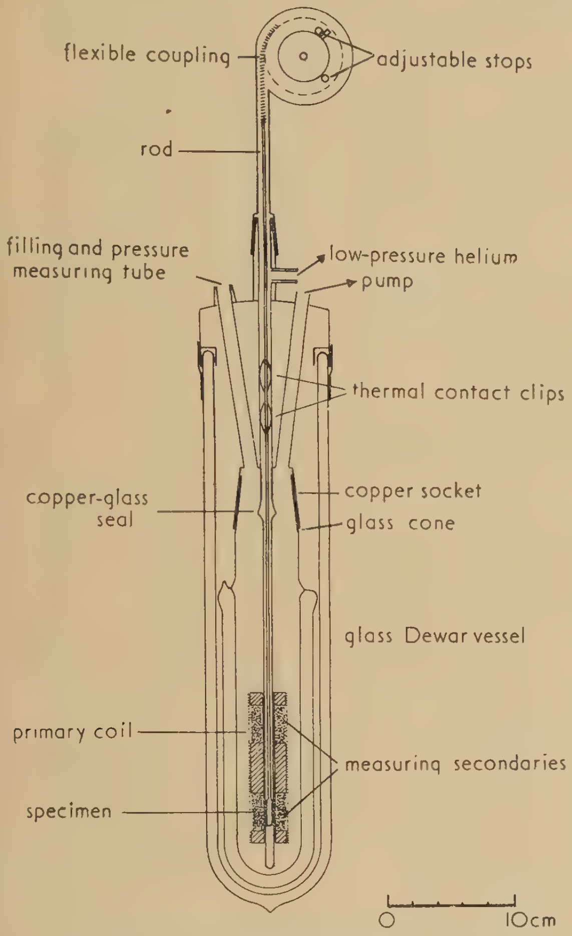

Fig. 1. Simplified diagram showing the construction of the cryostat (approximately to scale)

The measuring coil was surrounded by a Monax glass Dewar vessel into which liquid nitrogen, hydrogen or helium could be syphoned. The temperature of the specimen was varied by pumping the liquid and measured from the vapour pressure in a small tube dipping below the surface. It was found that thermal equilibrium could not be maintained when solid refrigerant surrounded the measuring coil. The temperature ranges with hydrogen and nitrogen were therefore limited to 20–14° K and 77–63° K respectively. The Dewar vessel was attached to the main apparatus by means of a ground glass cone fitting into a copper socket, using glycerol to make the joint vacuum tight when cold. The entire cryostat was surrounded by a second Dewar vessel which contained liquid hydrogen for experiments below 20° K, and liquid nitrogen for experiments between 77° and 63° K. In order to stop heat from room temperature reaching the cryostat down the Tufnol rod, two small spring clips were attached to it to make thermal contact with the surrounding German silver tube where this passed through the liquid refrigerant in the outer Dewar vessel. It was found that when the specimen was moved from the upper to the lower position the introduction of a warm section of rod slightly upset the thermal equilibrium in the inner Dewar vessel, and all measurements were therefore made by moving the specimen from the lower to the upper position.

(*b*) *The electrical circuit.* The mutual inductance was measured with a Hartshorn bridge similar to that described by Benzie and Cooke(2) using a tuned null detector of the type described by Erickson, Roberts and Dabbs.(3) The measuring frequency used was 175 c/s. The electrical circuit is shown diagrammatically in Fig. 2. The measuring coil was connected in opposition to an accurately variable mutual inductance, M_2, and the value for zero voltage in the secondary circuit found by using a cathode-ray oscilloscope to indicate the null point. The inductance M_2 consisted of five decades of secondary turns, wound on a common primary, the smallest unit being 0·015 μH. In practice there was also a small voltage in phase with the primary current due to eddy currents and stray capacitances in the measuring coil, and to losses in the specimen. This was balanced out with a potentiometer device P, coupling the primary and secondary circuits.

Because of the very large number of turns on the secondaries it was possible to increase the overall gain of the detector in the following way. When the coil is at room temperature the input impedance into the null detector is governed mainly by the resistance of the measuring coil secondaries. As the coil is cooled this resistance falls and the effect of the self-inductance becomes important. By tuning this inductance to resonate at the measuring frequency an increase of the input signal into the null detector can be obtained. Since the resistance is proportional to the number of turns, n, while the inductance is roughly proportional to n^2, a coil with a large number of secondary turns will have a large ratio of $\omega L/R$, which at low temperatures may considerably exceed unity. In particular, for the coil described above L was about 3 H

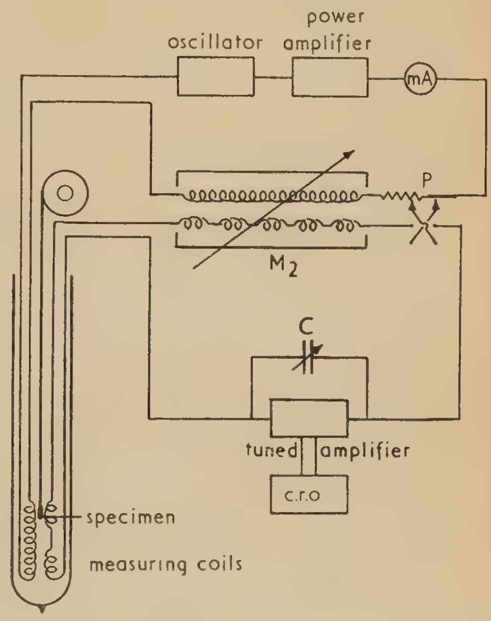

Fig. 2. Block diagram showing the electrical circuit

while the resistance at 20° K was 150 Ω, so that at a frequency of 175 c/s the ratio $\omega L/R$ was about 20. In computing the Q of the whole secondary circuit we must consider also the effect of the secondaries in the decade inductance box which are in series with those of the coil. In our bridge the inductance of these was negligible but the resistance was about 100 Ω, so that the Q of all the secondaries in series was about 12. By connecting a variable capacitor across the input terminals of the null detector, it was possible, therefore, to increase the input signal at 175 c/s by a factor of 12, at the same time discriminating against all other frequencies. At higher temperatures the Q falls off owing to the increase in resistance of the coil, but even at 77° K a gain of about two was obtained.

Tuning the secondaries also has the further advantage that the input transformer can be eliminated, since the impedance of a parallel tuned LC circuit is very high and no matching is needed into the first valve of the amplifier. It may be stressed that by connecting the capacitor in parallel with the whole of the secondary circuit the null point of the bridge is not affected, since the only effect of the capacitor is then to amplify off-balance signals.

One disadvantage of using a coil with a large number of turns is that the balance point of the Hartshorn bridge becomes both frequency and current dependent due to the effect of stray capacitances, and it is necessary to use a very stable oscillator. Furthermore, it was found that when the bridge was nearly balanced at 175 c/s, there remained a large uncompensated signal at 525 c/s which was due to about 1% harmonic distortion of the primary current. (Second harmonic distortion at 350 c/s was practically absent since a push-pull output stage was used in the oscillator providing the primary current.) In order to reduce this signal additional tuning was incorporated into the null detector in the form of a "twin T" rejection filter tuned to 525 c/s. This, together with the tuning at 175 c/s already present, allowed the final balance of the bridge to be made to within 0·01 μH.

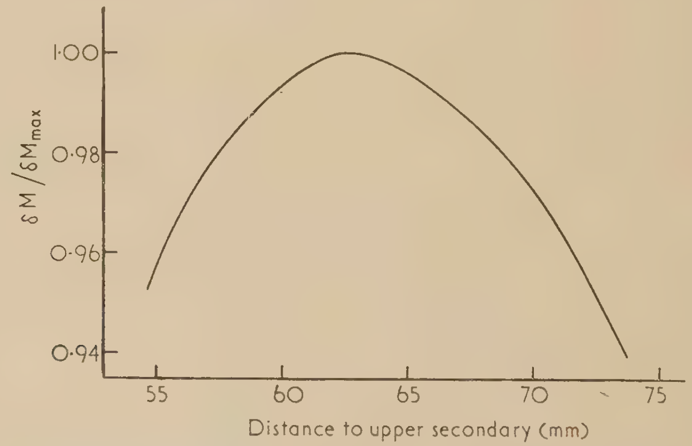

Fig. 3. Relative variation of δM when the specimen is moved from the centre of the upper half of the secondary coil to various positions inside the lower half

CALIBRATION AND PERFORMANCE

The sensitivity and reproducibility of the apparatus were investigated with a specimen of manganous ammonium sulphate, for which Curie's law is known to be closely valid over the whole temperature range of our measurements. For this substance the value of the molar susceptibility, χ_M, can be calculated theoretically, since it is known that the splittings of the $^6S_{5/2}$ ground state of the Mn^{++} ion produced by the electric crystalline field are very small ($\simeq 0{\cdot}3$ cm^{-1}),(4) and there are no excited states within 10 000 cm^{-1} of the ground state.(5) The susceptibility between 77° and 2° K is therefore given by

$$\chi_M = \frac{Ng^2\beta^2 S(S+1)}{3kT} = \frac{4{\cdot}375}{T}$$

where N is Avogadro's number, β the Bohr magneton, k Boltzmann's constant, $g = 2$ and $S = 5/2$.

At the lowest temperatures there is a small but appreciable deviation from this law, depending on the shape of the specimen and on the interactions between the paramagnetic ions. Since interactions are known to be small in this substance(6) and since the magnetic ions lie on a nearly cubic lattice, the effect can be calculated in terms of a simple demagnetizing correction θ, which changes the susceptibility law to the form

$$\chi_M = 4{\cdot}375/(T - \theta) \qquad (1)$$

The specimen used in the calibration experiments consisted of several small single crystals, weighing 0·1868 g, which were loosely packed into a cylindrical container 12 mm long and 5 mm in diameter. For this the calculated value of θ was $+0{\cdot}03$° K.

The first experiments consisted in locating the effective centres of the two halves of the secondary windings by adjusting the end stops until the change of inductance, δM, produced by moving the specimen from one half to the other, was a maximum. This adjustment was necessary not only to obtain maximum sensitivity, but also to ensure that the specimen was moved between two positions such that a small misplacement would have only a small effect on δM. The error likely to be caused by a misplacement was investigated by measuring the variation of δM as the position of one of the end stops was changed, the other remaining fixed. The results are shown in Fig. 3. It was found that near the centre of each half of the secondary there was a region about 2 mm long over which the variation of δM was less than 0·1% and that even 4 mm from the centre the change was ss than 1·5%. Since the movement of the specimen could controlled to better than 0·5 mm it was therefore to be kpected that any errors arising from misplacement of the pecimen would be entirely negligible.

The second series of experiments consisted in finding the onstant of proportionality relating changes of inductance as ıeasured on the Hartshorn bridge to absolute susceptibilities. If we put

$$A = \frac{\chi}{\delta M}\ \mathrm{cm}^3\ (\mu\mathrm{H})^{-1}$$

ıen, from equation (1),

$$A = \frac{4\cdot375w}{\delta M(T - 0\cdot03)W}$$

vhere w is the mass of sample, and W is the molar weight. Jsing this relation, values of A were calculated from measureıents of δM at different temperatures in the liquid nitrogen, ıydrogen and helium ranges. It was found that A was onstant over the entire range from 77 to 1·8° K to within % at a mean value $1\cdot63 \times 10^{-6}$ c.g.s. units of susceptibility per microhenry. The results of a typical run in the hydrogen ange, showing the spread of values around the mean, is hown in Fig. 4.

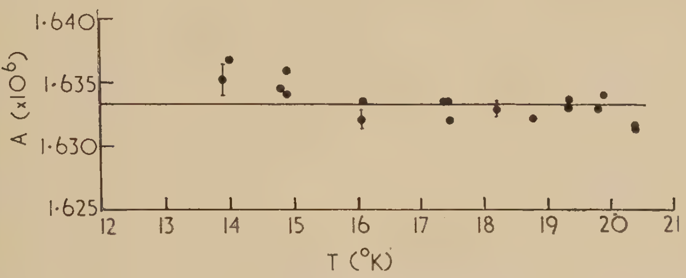

Fig. 4. Graph showing the spread of values in the determination of the factor A relating changes of inductance to absolute susceptibilities. The vertical lines indicate the uncertainty due to errors in the vapour pressure measurements

In experiments with magnetically strong specimens, such s the one described above, the only appreciable sources of rror arose from the measurement of temperature. Because f the fairly large heat influx to the cryostat it was difficult o maintain a completely stable equilibrium, and, with the xception of the range below the λ point of helium, small emperature inhomogeneities may have occurred. Further, it was difficult to calculate accurately the effect of the 'hydrostatic" pressure owing to the height of liquid above he coil. For a dense refrigerant, like liquid nitrogen, this orrection could amount to 1% in T. Finally, in the liquid ıydrogen range, there was a small error (of the order of ½%) n the vapour pressure–temperature relationship, due to ıncertainty in the ortho-para-concentration. From the onsistency of the above series of calibration experiments it vas concluded, however, that the combined error from all hese causes was less than 1%.

For small or weak specimens a more important source of rror arose from the uncertainty in the measurement of δM. For the bridge used the smallest detectable change of nductance was 0·015 μH corresponding to an uncertainty n the susceptibility of $2\cdot5 \times 10^{-8}$ c.g.s. units. For weak pecimens an important correction also arose from the small nagnetic effect of the polytetrafluorethylene box and Tufnol od. At temperatures in the liquid nitrogen and hydrogen anges this effect was usually diamagnetic in nature, but at lower temperatures small amounts of magnetic impurities gave rise to an overall paramagnetic effect. The magnitude of the correction could be reduced by careful cleaning of the box, using aqua regia, and in all cases it was possible to make the correction less than 3×10^{-7} c.g.s. units.

In its present form the sensitivity of this apparatus is still considerably less than that of the most refined Faraday methods.(7) However, for work at low temperatures where susceptibilities are usually large, this limitation is not very serious and is outweighed by the advantage of eliminating delicate moving parts. Owing to the simple and robust construction, it is possible to change specimens very easily, even when the cryostat is at a low temperature, and no adjustments have to be made between experiments. One limitation of the method is that it is unsuitable for the measurement of metals or conducting alloys because of the effects of eddy currents produced by the a.c. measuring field. These could be reduced by using a lower frequency but this would result in a considerable loss of sensitivity. However, for paramagnetic salts this difficulty does not arise.

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A 100 kV compressed-gas standard capacitor

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The construction of a reference standard capacitor of value 99·2 pF having nitrogen at 120 lb/in.^{2} as dielectric and suitable for use at voltages up to 100 kV (r.m.s.) is described.

The method of measurement of the interelectrode capacitance and the effect of eccentricity of the cylindrical electrodes are also considered.

Compressed-gas capacitors have been fairly widely used for many years as reference standards for high-voltage Schering bridges.(1) There have, however, with the notable exception of two recent papers by Keller,(2,3) been few published descriptions of their detailed design and little mention of the difficulties of construction. Modern capacitors of this type are generally of fixed value with a concentric-cylindrical electrode arrangement using an inert gas at 10 to 15 atm pressure as a dielectric. Such a capacitor, designed for use with a doubly-screened Schering bridge,(4) and which has recently been constructed, is described in this paper. It has a capacitance of 99·2 pF, is filled with nitrogen at 120 lb/in.^{2} and is suitable for use at voltages up to 100 kV.

CONSTRUCTION

A cross-sectional elevation of the capacitor is shown in Fig. 1. The pressure vessel containing the electrodes comprises a bakelized paper tube *A*, 4 ft long, having cast brass flanges *B* to each of which is bolted a mild steel end disk. Nebar jointing rings *C* provide gas seals between the disks and the faced ends of the insulating tube. It was originally intended that the brass flanges should be secured to the tube simply by the lateral pressure created by tightening the tapered rings *D*. When nitrogen was admitted to the vessel, however, after a satisfactory hydraulic test up to 200 lb/in.^{2} with clean transformer oil, it was found that pressure could not be indefinitely maintained. Insufficient gasket pressure and porous brass castings were found to be the cause of this. By bonding the castings to the tube with Araldite, which set under pressure from the tapered rings, complete gas-tightness was ensured with considerable additional joint strength. A pressure of 120 lb/in.^{2} of nitrogen has remained constant, except for small variations due to changes of ambient temperature, in the completed capacitor for several months.

The cylindrical electrodes are of hard-drawn brass tube. The outer, or high-voltage electrode *E*, is $25\frac{1}{2}$ in. long and has a hand-polished inside surface 5 in. in diameter. A support ring is brazed to the upper end of this electrode so that it may fit the brass sleeve *F* fitted concentrically into the paper tube. The electrode is a sliding fit in this sleeve and may be withdrawn vertically from it if necessary. To avoid excessive concentration of electric stress, a ring bent from $\frac{1}{2}$ in. diameter brass rod is brazed to the lower end of this electrode. The inner, or low-voltage electrode *G*, has a turned and polished outer surface $3\frac{3}{4}$ in. diameter. It has a linear surface length of $18\frac{1}{2}$ in. and hemispherical end caps. This electrode is supported at its upper end by a vertical, earthed, 1 in. diameter brass tube, but is insulated from it by Tufnol spacers *H* and *J*. The cylindrical pedestal *K* bolted to the lower end disk of the pressure vessel forms a rigid base for the whole low-voltage assembly. Despite care in accurately centring this pedestal on the disk, slight eccentricity of the electrodes has occurred. The effect of this eccentricity on the maximum electric stress in the capacitor is small (see Appendix).

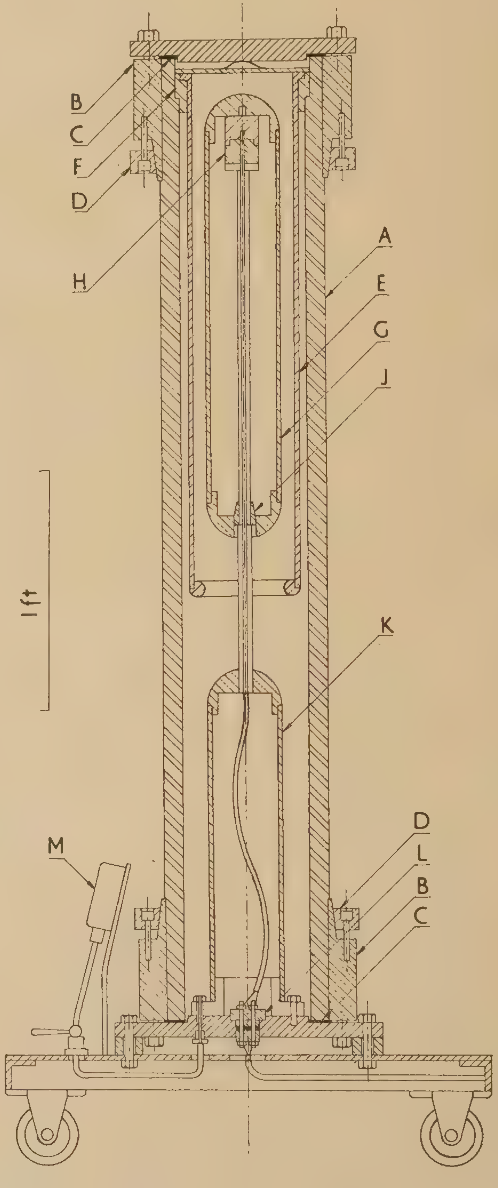

Fig. 1. Cross-sectional elevation of capacitor

A two-way insulated and pressure-tight connector *L* is fitted in the lower end disk. It comprises two pieces of Tufnol turned to fit a stepped hole in the disk and bolted together compress a rubber ring which forms the gas seal. The 'o bolts allow electrical connexions through the base of the ssel. A screened, single-conductor cable passes through e tube supporting the low-voltage electrode assembly and lows a connexion from the low-voltage electrode to be ought to one of these bolts. The screen of the cable is sulated from the earthed support tube and is connected to e other bolt to form part of the inner screen of the bridge. ıe low-voltage electrical connexion to the capacitor is made rough a screened socket mounted on the side of the trolley ıse. Also mounted on the base is a four-way junction and /o stop-cocks for the gas supply to the vessel. With this rangement, connexion may be made to a cylinder of com- essed gas, a rotary vacuum pump and to a pressure gauge so that the vessel may be evacuated and then flushed with ıs before being filled with gas to the required pressure.

EASUREMENT OF INTERELECTRODE CAPACITANCE

The schematic diagram of the capacitor shown in Fig. 2 ay be simplified to give the equivalent circuit shown in ig. 3(*a*). In this circuit C_1 (the interelectrode capacitance), $_3$ and C_4 have fixed values which depend on the geometry f the electrodes and their supports. Capacitors C_2 and C_5, owever, depend on the position, relative to neighbouring arthed objects, of the high voltage terminal and the low oltage screened lead respectively. Special care had to be aken, therefore, to ensure that they remained constant during he measurement period. Measurements of these values of apacitance were made at 750 c/s against a Campbell mutual ıductometer, using a modified Carey–Foster's bridge onnexion.(5) The terminal of the oscillator supplying the ridge, which was connected to the capacitance being ıeasured, was also connected to the earthed trolley base, o that all measurements were made with respect to earth. 'he measurements were made in two stages as follows. Capacitor C_5 was first shorted to reduce Fig. 3(*a*) to the delta-connected circuit shown in Fig. 3(*b*), in which $C_3' = C_3 + C_4$. By short circuiting each branch of this circuit in turn and measuring the capacitance of the remaining two branches in parallel, the individual values of C_1, C_2 and C_3' were determined. A second delta circuit, Fig. 3(*c*), was then formed by earthing the high voltage terminal and the branch values C_3'', C_4 and C_5 were obtained in a similar way. The table below shows the results obtained for a gas pressure of 120 lb/in.^{2}

$C_1 = 99{\cdot}2$ pF
$C_2 = 320$ pF
$C_3' = 591$ pF
$C_4 = 348$ pF
$C_5 = 143$ pF
$C_3'' = 342$ pF

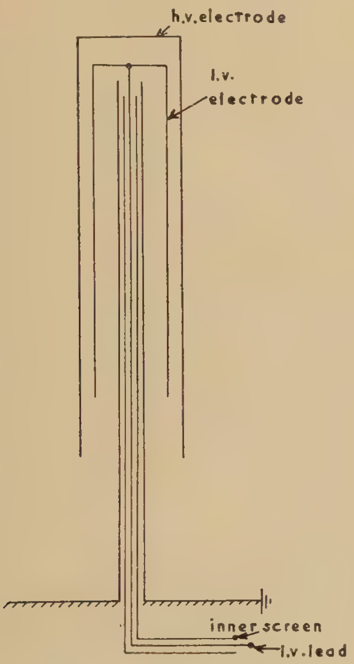

Fig. 2. Schematic diagram of capacitor

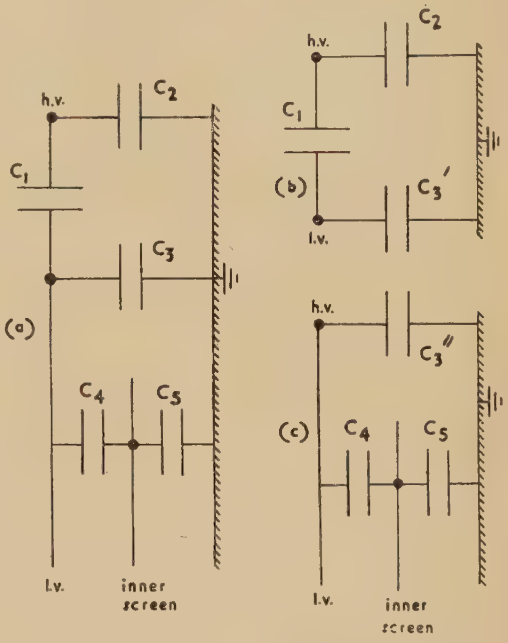

Fig. 3. (*a*) Equivalent circuit of capacitor. (*b*) Equivalent circuit with C_5 shorted. (*c*) Equivalent circuit with C_2 shorted

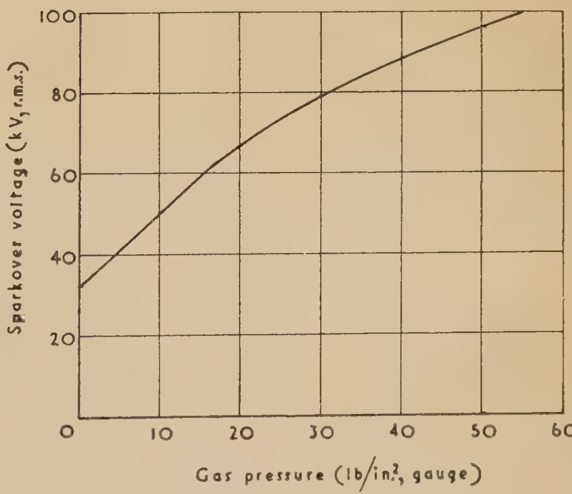

Fig. 4. Variation of r.m.s. sparkover voltage with gas pressure

It will be noted that a check on the consistency of measurement is obtained by separately evaluating C_3 from the expressions $C_3 = C_3'' - C_1$ and $C_3 = C_3' - C_4$ to give 242·8 and 243 pF respectively.

The effect of gas pressure on the interelectrode capacitance was determined by similar measurements at various pressures from 120 lb/in.^{2} to atmospheric pressure. An approximately linear decrease of capacitance was obtained with a total change of less than 0·5 pF. Since the change of pressure from the normal value of 120 lb/in.^{2} due to change of ambient temperature is unlikely to exceed 5 lb/in.^{2}, the effect on the interelectrode capacitance from this cause may, therefore, be considered negligible.

The variation of sparkover voltage (obtained after spark conditioning of electrodes) with gas pressure up to the maximum available voltage of 100 kV (r.m.s.) is shown in Fig. 4. Extrapolation of this curve shows that a generous margin exists between the maximum working voltage of 100 kV at 120 lb/in.^{2} and the sparkover voltage at that pressure.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the advice of Mr. W. C. Barry of W. T. Henley's Telegraph Co. Ltd. and the interest and encouragement of Prof. B. Hague, in whose Department the capacitor was made. Thanks are also due to Mr. W. Butler for his skill in constructing the capacitor.

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APPENDIX

Dawes(6) shows that the maximum stress $\mathscr{E}_{max}$ in an eccentr circular cylindrical capacitor (ignoring end effects) havin electrodes of radii b and $a(b > a)$ and an eccentricity c, t which a voltage V is applied is:

$$\mathscr{E}_{max} = \frac{V(a^2 - p^2)}{a(a^2 + p^2 - 2ap)\cosh^{-1}\beta}$$

where $p = \dfrac{m}{2c} - \sqrt{\left[\left(\dfrac{m}{2c}\right)^2 - a^2\right]}$, $m = b^2 - a^2 - c^2$

$$\text{and} \quad \beta = \frac{b^2 + a^2 - c^2}{2ab}$$

By substitution this may be reduced to

$$\mathscr{E}_{max} = \frac{V}{a\cosh^{-1}\beta}\,\frac{\sqrt{(m^2 - 4a^2c^2)}}{m - 2ac}$$

Putting $c = ka$ and neglecting terms involving k^2 and highe orders of k, we get

$$\mathscr{E}_{max} = \frac{V}{a\cosh^{-1}\left(\dfrac{b^2 + a^2}{2ab}\right)}s = \frac{V}{a\log_e\dfrac{b}{a}}s$$

where $$s = \frac{b^2 - a^2}{b^2 - a^2(1 + 2k)}$$

is the factor by which the maximum stress occurring in concentric cylindrical capacitor must be multiplied to obtai the maximum stress occurring when the electrodes are sligh eccentric.

When applied to the capacitor described here we ge $s = 1{\cdot}0139$, i.e. less than 1·5% increase of stress for a eccentricity of 0·01 in. Even with an eccentricity as great a 0·1 in. there is only a 16% increase of maximum stress o the concentric value of 73 kV/cm.

It is perhaps of interest to note that the change of calculate capacitance with eccentricity is even less significant. Thus for eccentricities of 0·01 and 0·1 in. the increases of capacitance calculated from Dawe's equation, are less than 0·1 and 0·5% respectively.

Laboratory and workshop notes

A microscope stage fibre extensometer

By E. H. Andrews, B.Sc.,* Imperial Chemical Industries Ltd., Harrogate, Yorkshire

[*Note first received* 31 *July, and in final form* 3 *October*, 1956]

he microscopic appearance and optical properties of textile bres often afford a convenient means of characterization, nce they reveal to a greater or lesser extent the internal and irface structures of the material under examination. If ress is applied to the fibre, however, its optical properties ill, in general, be modified owing to deformation and ltimate breakdown of the fibre structure, and the possibility rises of tracing these structural processes by observing the ecimen under various conditions of strain. The extenso- ieter stage was designed with this purpose in view, it being articularly required to measure the diameter and bire- ingence of melt spun polymer fibres as functions of the pplied strain. Crawford(1,2) and Kolsky(1,3) have published ork of this nature in which the relationship between stress, rain and birefringence was obtained for a number of olymers, but their investigation was limited to non-fibrous iaterial and generally low strains.

The design of the instrument was governed by the require- ient that a filament of diameter 20–50 μ might be stretched o any desired, accurately determined extension (up to 00%), whilst remaining all the while under microscopic bservation. This object has been achieved by using the istrument described in conjunction with a Cooke, Troughton nd Simms polarizing microscope, a magnification of at least <200 and a rotating stage being required. The extensometer ; attached to this stage by means of two small thumb screws, he necessary tapped holes being already present; one of the crews passes through a slot (*A* in Fig. 1) in the extensometer n order to provide some lateral movement of the instrument.

The extensometer itself, shown in Fig. 1, consists essentially f a metal slide *B* running in a thin metal frame 4¼ in. in ength, 1⅛ in. in width and ⅛ in. deep. The slide is driven y a micrometer screw, the movement of which is measured n the normal way, the micrometer drum being arranged to ie just clear of the edge of the microscope stage. The outer rame is so constructed that an ordinary glass slide fits neatly into it from below, its upper surface *C* almost touching the metal slide. This arrangement brings the mounted filament close and parallel to the glass plate, making it possible to use an immersion fluid without which accurate measurement of diameter is impossible.

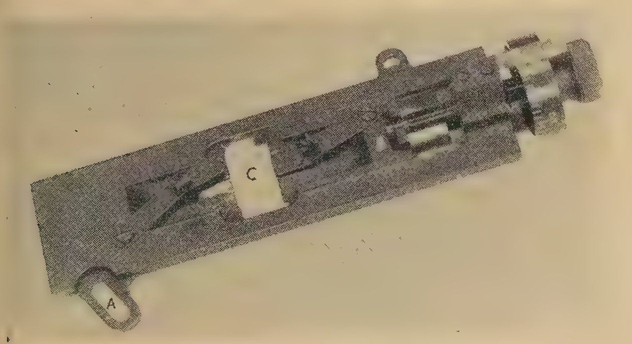

Fig. 1. Microscope stage fibre extensometer

The filament is held between two spring clamps, one attached to the outer frame and one to the micrometer slide, the minimum distance between the clamps being 1·0 cm to allow the microscope objective to be brought down close to the specimen. The total travel of the slide is just over 1·0 cm or 100% and its position may be read to a nominal accuracy of better than 10^{-3} cm or 0·1% of the original length. In fact, the zero setting and backlash at the micrometer-slide joint increase the error to some ±0·1%, but as the extension to break of the fibres under examination is rarely less than 12%, the uncertainty is of small importance.

The clamps are spring loaded with self-alining jaws loosely attached to the springs as indicated in Fig. 2. Each loose jaw is furnished with a replaceable lining of polyvinyl chloride which ensures even pressure and minimizes slipping.

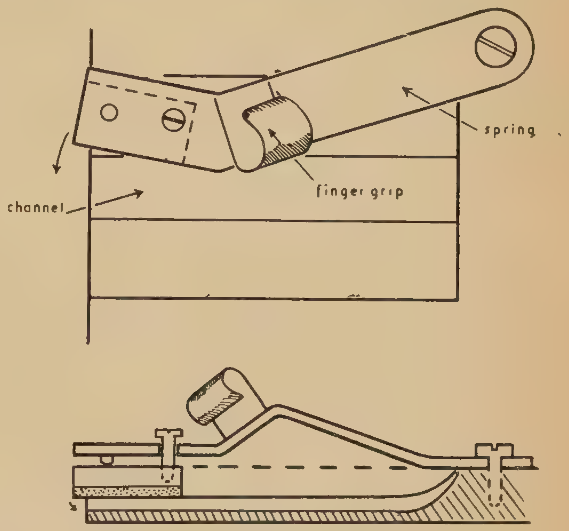

Fig. 2. The fibre clamps

In use the extensometer is screwed to the rotating stage of the microscope and set to zero extension. The moving jaws of the two clamps are lifted out of the grooves and pushed to one side whilst the filament, under a very slight tension, is placed in position; the jaws are then carefully returned to their place. After a little practice the operator can accomplish this mounting quickly and without damage to the fibre. If immersion of the specimen is desired, a drop of fluid is placed on the glass slide so as to cover the filament along part of its length; the drop is not spread out, and no cover glass is used. The microscope may now be focused, the filament being brought into view by lateral adjustment of the extensometer and set at the required angle with respect to the cross wires by rotation of the stage. The extensometer is now fastened rigidly in position by tightening down the thumb screws and the filament extended by rotation of the micrometer drum, whilst measurements of diameter and birefringence are made in the usual way.

Since only one end of the filament is in motion the point of observation changes continually, constituting an obvious disadvantage if inhomogeneities exist in the sample. This is rarely serious when dealing with melt spun synthetic fibres, since their uniformity is good, but difficulty would be encountered in examining less regular materials. The moving point of observation is also troublesome in the inspection of a stretched filament for localized structural changes, but in this case an even greater disadvantage is the limited field of view. It has been the practice in such work as this to free the extensometer completely from the microscope table by removing the screws, and to manipulate it by hand, thus making it possible to view the whole length of the filament. Clearly an improved design could provide for longitudinal movement of the extensometer as a whole, but this has not yet been undertaken.

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* Now at The British Rubber Producers' Research Association, Welwyn Garden City, Herts.

The author wishes to thank Mr. E. Bakker and Mr. F. Mallet for their helpful suggestions and for the actual construction of the instrument.

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A technique for sealing aluminium–silicon foils to glass X-ray cameras

By P. J. C. Kent, Fulmer Research Institute Ltd., Stoke Poges, Bucks

[*Note received* 23 *July*, 1956]

The advantages of using aluminium–silicon foil as a window material for high temperature X-ray cameras have been described by Provan, Shaw and Williams.* This type of window has now been used on a variety of cameras including some made entirely of glass. Initially the aluminium–silicon was bonded to the camera by means of thermo-setting plastic. However, this method has two serious disadvantages. The plastic sets a low limit to the degassing temperature and the slow continuous degassing which takes place requires frequent gettering if used on a sealed-off system. Experiments were made with a view to finding a method for bonding the windows directly to the glass body of the camera. This has now been achieved, the resulting seal being robust and vacuum tight.

The aluminium–silicon foil is joined to soda glass using No. 93 glass (supplied by British Thomson-Houston Ltd.) as the intermediate bond. The soda glass is most conveniently joined to borosilicate glass, if this is used for the body of the camera, by building up a graded seal on the side of the borosilicate tube, in the form of a T-piece, terminating in a soda glass flange (see left-hand side of figure). No. 93 glass, which is available in the form of a fine powder, is mixed with water to give a thick paste, when required, and any remaining mixture discarded. The paste is painted around the flat face of the flange and the circle of foil, approximately $\frac{1}{8}$ in. smaller in diameter than the flange, is carefully lowered on to it. When the paste has dried off, a thin ring of paste is painted around the foil extending about $\frac{1}{16}$ in. over the edge (see right-hand side of figure). The seal is completed by placing the camera, with the foil in a horizonta position in an annealing oven, and slowly raising the temperature to 480° C. The No. 93 glass will now melt completing the bond. After about 20 min the seal is allowed to coo slowly to room temperature.

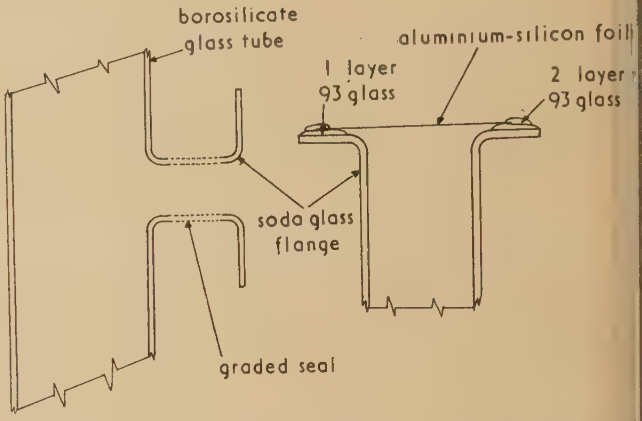

Diagram showing method of sealing aluminium–silicon foil to glass X-ray camera

When several windows have to be sealed to one camera, only one foil should be bonded at a time. After the bonding glass has been fused the completed flange can be hung down if necessary when sealing the other windows. In the rare case of a seal not being vacuum-tight a further application of paste in the vicinity of the leak with subsequent firing will usually effect a cure.

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* Provan, A. G., Shaw, B. A., and Williams, G. I. *J. Sci. Instrum.*, **33**, p. 445 (1956).

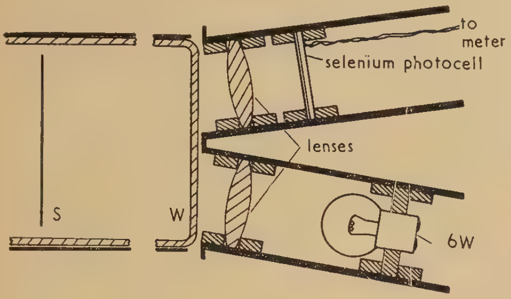
Simple double-path densitometer for controlling thickness of evaporated films

By N. A. Slark, B.Sc., A.R.C.S., Imperial College of Science and Technology, London, S.W.7

[*Note received* 30 *July*, 1956]

In manufacturing photoelectric tubes such as photomultipliers, image converters and television camera tubes a thin semi-transparent layer of antimony, bismuth or silver is frequently evaporated on to a window to form part of a photocathode. For example, in processing a transparent antimony-caesium photocathode the layer is antimony. The thickness is very important as it controls the final sensitivity but if the optical transmission, which gives a measure of the thickness, is judged by eye, consistent results are difficult to obtain. A convenient way of measuring the transmission is by projecting a beam of light through the layer on to a photocell. It often happens, however, that owing to the construction of the tube the walls are obscured and this method cannot be used. The densitometer described has been designed to overcome this difficulty.

The figure shows the densitometer in place on the front end of an electron tube. Light from the 6 W bulb passes through the lens, the flat glass window *W* and the antimony layer to give a diffuse patch covering the flat surface *S*. Light reflected from this surface passes back through the antimony layer, the window *W* and the lens and falls on a selenium barrier layer photocell, the output from which is measured by a microammeter or a galvanometer. If the flat ırface S is not available inside the tube the light may be :flected from the walls or any other electrodes inside the ıbe. The only requirement is that the reflectivity of these ırfaces is not affected by the evaporation. If the surface sed is a good reflector, the photocell current is of the order f 100 μA and a relatively simple meter will suffice. With ss favourable conditions a more sensitive meter or a alvanometer may be required. The two tubes containing he bulb and the photocell are inclined so as to cover the ame field of view at the surface S, and are mounted in a at metal plate which makes contact with the glass window o prevent direct external reflexion from the source to the etector. The reading of the microammeter is noted before ommencing evaporation and then the antimony is evaporated ıntil the microammeter reading has fallen to a predetermined alue.



Double-path densitometer

The response of the selenium cell used in this way is linear, nd as the light traverses the antimony layer twice the micro-mmeter reading is proportional to the square of the trans-nission. This square law gives twice the sensitivity, and herefore half the error, of methods in which the layer is raversed only once. Using this instrument it is possible to vaporate a layer to within 1% of the percentage transmission lesired and thus to control exactly the thickness of the ıntimony layer in all photocathodes produced.

A centrifugal magnetic circulating pump for a totally enclosed diffusion cell

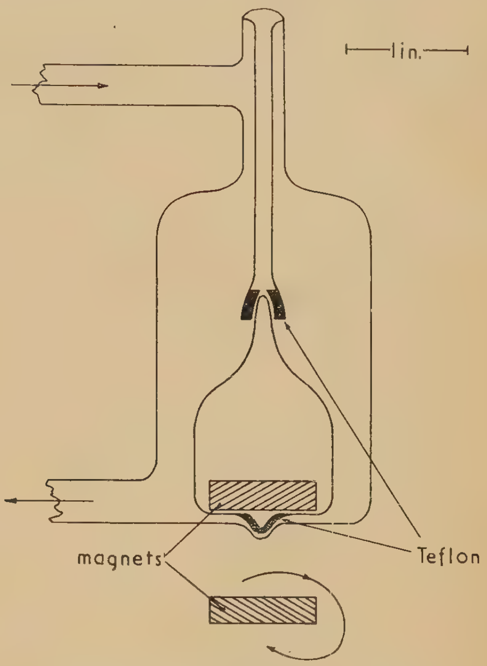
By F. Bond, Wool Industries Research Association, Torridon, Headingley, Leeds

[*Note received* 3 *October*, 1956]

In a recent series of investigations of ionic diffusion a circulation pump was required in an all-glass apparatus of approximately 200 ml. capacity. The following arrangement was found to be satisfactory.

A small bar magnet is fitted into a Pyrex glass tube of shape as shown in the figure, and this in turn is sealed into an outer glass envelope, the inner tube pivoting freely in glass bearings. The pump and diffusion cell are suspended in a water bath, a second magnet being rotated outside the tank by a variable speed motor. Liquid in the outer envelope is forced, due to centrifugal action, through the lower side arm and round the diffusion cell irrespective of the direction of rotation of the magnet. A typical pump of the dimensions given with the magnet rotating at 120 rev/min gives a flow rate of approximately 2·4 ml./s through a 30 cm glass tube approximately 0·75 cm diameter. In an earlier model a four-bladed glass propeller was sealed above the enclosed magnet but it was found to be unnecessary.

The figure shows a pump which has been modified to eliminate possible wear on the glass bearings and to obtain a smoother action. A Teflon spigot is made a push fit on the lower end of the inner tube, while the other end runs in a Teflon cylinder, this material being used because of its low friction and inert properties.



Centrifugal magnetic circulating pump

On the high residual pressure obtained during the activation of valves containing oxide-coated cathodes

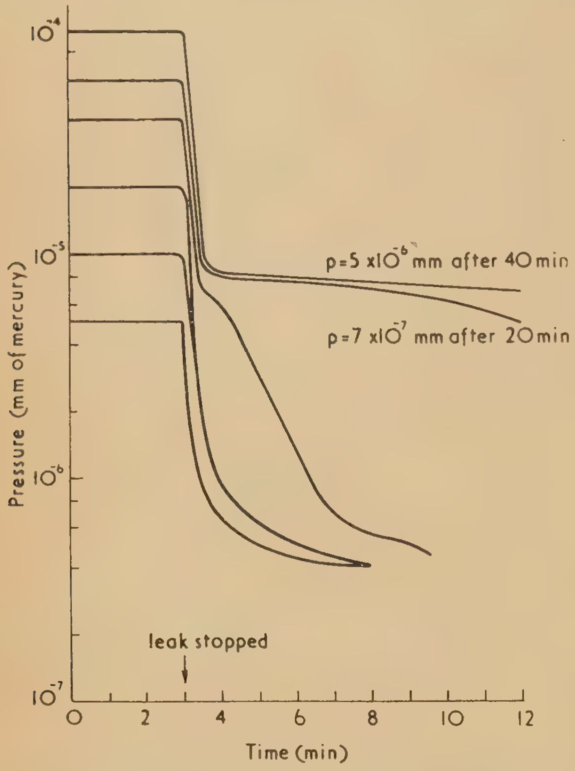
By H. J. Curnow, B.Sc., Services Electronics Research Laboratory, Baldock, Herts.

[*Note received* 16 *August*, 1956]

During the processing of valves containing oxide-coated cathodes it is necessary to heat the cathodes to produce the oxides, which form the active constituent, from the carbonates which are originally present. In this process gas is driven off from the valve components and carbon dioxide is evolved from the reacting carbonates. It was observed that in some cases the pressure in the vacuum system did not fall after the activation of such a cathode to as low a value as had been obtained previously. Usually the initial pressure was below 10^{-7} mm of mercury, but afterwards it would remain at about 6×10^{-6} mm of mercury for several hours. This value was obtained quite consistently with many valves pumped with mercury-vapour pumps using a cold trap cooled with liquid oxygen. The effect was never observed with an oil diffusion-pump, which required no cold trap. It was thought undesirable to operate valves on the pump in such a poor vacuum, so the origin of the effect was sought.

The effect was attributed to the condensation in the cold trap of a substance with a vapour pressure at the cold-trap temperature (−183° C) of the observed value. By making a series of valves containing various parts it was found that the source of the gas lay in the cathode itself. It then appeared that the most likely substance was carbon dioxide, which has a vapour pressure* of 2×10^{-5} mm at −183° C.

To confirm this, a series of tests was made simulating the activation of a cathode, but introducing carbon dioxide gas from a cylinder into the system through a leak. The variations of the pressure, indicated by an ionization gauge, were identical with the variations observed when cathodes were activated. The pressure tended to remain around 6×10^{-6} mm of mercury, provided that it had previously been raised above 2×10^{-5} mm (see the figure).



Variation of pressure with time, after introduction of carbon dioxide

It was concluded from these tests that if high residual pressure is to be avoided care must be taken to prevent condensation of carbon dioxide in the cold trap. This requires that the rate of evolution of carbon dioxide during activation should be kept down so that the pressure in th system never exceeds 2×10^{-5} mm of mercury. This migh impose some considerable restraint on the activation o cathodes, especially those containing a large amount o active material. The effect may be avoided by using an o diffusion-pump, with which a cold trap is not required excep to obtain the very best vacuum in the later stages of processing Another method would be to use a cold trap at a slightl higher temperature: raising the temperature by only 20° C would allow pressures during activation up to 5×10^{-3} mm of mercury, but care would have to be taken that othe adverse effects did not follow.

Whether this high residual pressure has any influence on the operation of valves could only be settled by extende tests; experience so far has been limited to a small numbe of experimental valves. It seems likely that the main effec would arise through operating the valve on the pump in the poor vacuum, which might lead to excessive ion bombardment of the cathode.

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* *International Critical Tables*, Vol. 3, p. 207 (New York: McGraw-Hill Book Co. Inc., 1928).

Preparation of seed crystals

By G. W. Green, Radar Research Establishment, Great Malvern, Worcs

[*Note received* 22 *August*, 1956]

Single crystals of semiconductor materials are usually grown by the Czochralski method, for which seed crystals are required. With hard materials, such as silicon and germanium, the usual and somewhat laborious procedure for making seeds is to cut a crystal, at the required angle to a surface of measured crystallographic direction, into square section bars. These are then ground to fit a holder.

An easier and much quicker method is to use as seeds the cores obtained by drilling the material with a hollow, thin-walled diamond drill. After etching to remove the worked layer, the seeds are fitted into a holder without further mechanical treatment. Seeds of ¼ in. diameter and 1 in. long have been made without difficulty by this means. Drills of various sizes are obtainable commercially from Impregnated Diamond Products Ltd., together with suitable adaptors for introducing a coolant (such as tap water), by means of which the drills may be used in an ordinary workshop drilling machine.

Orientation of the seeds is also achieved easily by this method. Once a flat surface, orientated by X-rays perpendicular to the required seed axis, has been ground on the crystal, no further measurement is required; the crystal is mounted on this face on the drilling machine table and the accuracy of orientation of the seeds is then determined only by the machine.

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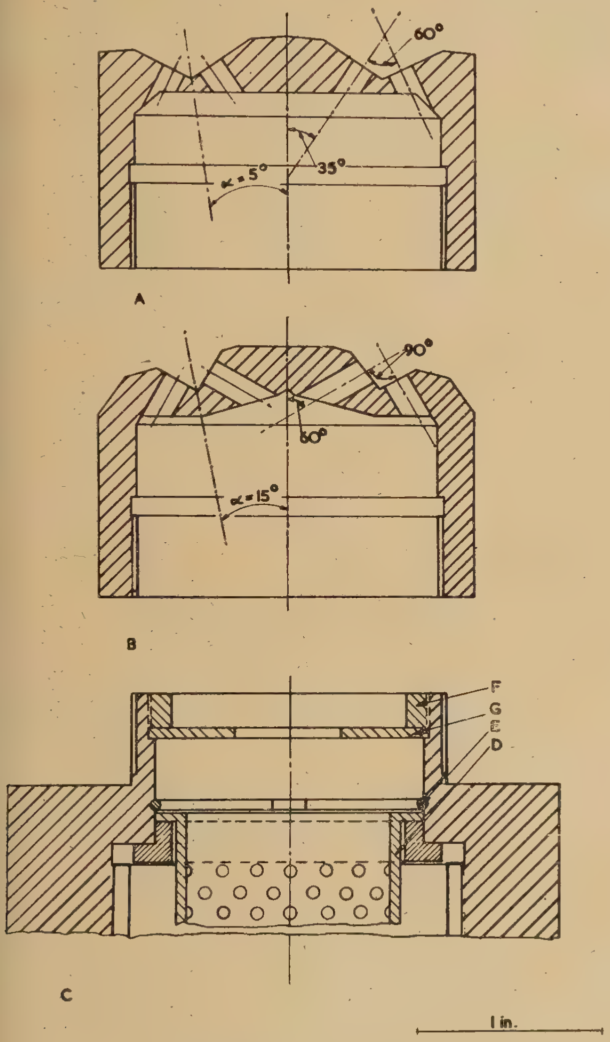
Correspondence

Control of the distribution of a spray projected to an area

the course of experiments on the extinction of fires with ater sprays, a simple method was found for controlling the stribution of a spray delivered to an area. This method, ich is based on the use of pressure nozzles in radially ranged pairs of impinging jets, is illustrated by considering o nozzles *A* and *B* (see the figure). Both nozzles contained pairs of 9/64 in. impinging jets. Nozzle *B* gave a wider ne of spray than nozzle *A*, primarily because of the larger ngle α between the axis of the nozzle, and the surface bisect- g the angles between the pairs of jets. The nozzles were tted to a 1½ in. supply line by an adaptor *C* fitted to the lter *D* retained by a circlip *E*. Provision was also made for e insertion into the adaptor of an orifice plate *G* which ould be secured by the locking-ring *F*.

The distribution of spray from these nozzles in a horizontal lane 8 ft below the nozzles was determined by measuring



Sectional view of nozzles

A, narrow angle nozzle; *B*, wide angle nozzle; *C*, nozzle adaptor

Spray distribution from multi-impinging jet nozzles. Rates of flow and coefficients of variation

Type of nozzle	Control device	Water pressure (lb/in.²)	Delivery (gal/min)	*Distance from centre of sprayed area (ft)* 0	1		2		3		4		5		6		7	
				(gal ft−2 min−1)	Mean* (gal ft−2 min−1)	Coeff. variation	Mean	Coeff. variation	Mean	Coeff. variation	Mean	Coeff. variation	Mean	Coeff. variation	Mean	Coeff. variation	Mean	Coeff. variation
Narrow angle	None	25	19·4	6·54	1·13	0·43	0·398	0·68	0·145	1·10	0·031	1·64						
		50	28·2	14·70	2·10	0·64	0·716	0·83	0·276	1·17	0·027	2·24	—	—	—	—	—	—
		90	37·2	15·40	1·63	0·22	0·818	0·95	0·265	1·25	0·016	0·53						
	9/16 in. orifice plate	25	18·6	0·400	0·419	0·10	0·616	0·096	0·269	0·43	0·0263	0·28	0·0026	0·29				
		50	25·7	0·500	0·914	0·15	0·980	0·173	0·203	0·36	0·0244	0·35			—	—	—	—
		90	33·4	2·280	2·281	0·17	1·158	0·634	0·085	0·56	0·0044	0·20						
Wide angle	None	25	19·1	3·02	0·583	0·38	0·215	0·47	0·125	0·24	0·080	0·92	0·046	0·79	0·012	0·88		
		50	26·3	5·09	1·049	0·36	0·376	0·53	0·195	0·91	0·108	0·85	0·046	0·96	0·014	0·93	—	—
		90	35·4	10·40	1·208	0·48	0·457	0·82	0·258	0·98	0·145	1·28	0·060	1·60	0·008	1·88		
	9/16 in. orifice plate	25	17·7	0·270	0·162	0·066	0·153	0·12	0·165	0·19	0·163	0·22	0·124	0·36	0·053	0·48	0·010	0·33
		50	24·1	0·277	0·285	0·079	0·284	0·20	0·279	0·32	0·211	0·37	0·119	0·50	0·040	0·59	0·008	0·67
		90	31·1	0·625	0·612	0·061	0·564	0·21	0·425	0·50	0·200	0·78	0·072	0·88	0·016	1·05	0·002	1·58

* Each mean is based on eight readings.

the rate of flow at the centre of the spray and at radial distances increasing in units of 1 ft on eight equally spaced radii. The table shows the mean value and the coefficient of variation (standard deviation/mean) of the rate of flow at different radii for the two nozzles, with and without orifice plates at nozzle pressures of 25, 50 and 90 lb/in.^{2}. The total delivery from the nozzles is also shown. The table shows, as expected, that a larger area of spray-coverage was obtained with the wider angle nozzle. However, for both nozzles at all pressures there was a very dense core at the centre of the sprays when no orifice plate was used with the nozzles; this core disappeared almost completely when an orifice plate was used. Under the latter conditions, there was a fairly uniform distribution of spray at an appreciable distance from the centre. The coefficient of variation at a given radial distance was also considerably smaller when the orifice plate was used.

The effect of the orifice plate may be accounted for as follows. The spray consisted predominantly of six dense plates of spray formed in the vertical planes bisecting the angle between the planes containing adjacent pairs of jets. When no orifice plate was used the plates of spray met at the axis and gave there a very high concentration of spray. When an orifice plate was used, however, the water reached the inner holes of each impinging jet pair at a higher velocity than it reached the outer holes, because the inner holes were much nearer the orifice. Thus the jets of water coming from the outer holes had a lower velocity than those from the inner holes. This caused a sufficient divergence of the plates of spray away from the axis of the nozzle to prevent these plates meeting on the axis.

By using various orifice plates it should be possible to control the distribution of spray between limits of a highly peaked type of distribution and a uniform or even slightl hollow distribution. Variation in the total flow rate of th nozzles may also be achieved by varying the number or th diameter of the jets used. The area of coverage from a sing nozzle may also be varied by changing the angle α and als the angle of impingement between the jets.

The work described in this letter forms part of the pro gramme of the Joint Fire Research Organization of th Department of Scientific and Industrial Research and Fir Offices' Committee; the letter is published by permission o the Director of Fire Research.

The nozzle caps are based on a design by Mr. P. M. T Smart. The writers wish to thank Mr. P. S. Tonkin an Mr. G. Hall who helped to carry out the measurements.

Fire Research Station,
Boreham Wood,
Herts.

D. J. Rasbash
G. W. V. Stark
(25 September, 1956

A water-driven device for filling, aerating and agitating bath

It has been brought to my notice that it might appear from part *A* of the figure in my note published on p. 320 of the August 1956 issue of this *Journal* that the pressure of the piston on its downward stroke might close the bottom outlet coil of the tube before all coils higher up are emptied. This does not occur. Owing to the tube lying at an angle to the surface of the piston it is progressively closed through out its whole length from above downwards.

University of Wales,
Cardiff.

A. L. Sims
(26 November, 1956

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

Automatic power plant and control switch-gear. Austinlite Ltd., Crawley, Sussex. An attractively produced book containing 39 pages of text and illustrations deals with the problems encountered in the provision of automatic power plant and the solutions which this company has applied to them.

Precision instrument components. PIC Design Corp., 477 Atlantic Avenue, East Rockaway, Long Island, New York, U.S.A. A 128-page illustrated catalogue No. 11 classifies over 4000 precision instrument and servo-parts which this company has available from stock. The catalogue also contains engineering data for use in the electronic and instrumentation fields.

Interference microscope. C. Baker Ltd., Metron Works, Purley Way, Croydon, Surrey. An 8-page leaflet gives details of the surface-finish interference microscope which has been constructed to meet with the demand for surface finishes of high quality and precision methods of assessment and control.

Nickel plating. The Mond Nickel Co. Ltd., Thames House, Millbank, London, S.W.1. A 72-page illustrated publication entitled *Nickel plating for engineers* has been written primarily for engineers, designers and others who are interested in the possibilities which plating offers in design.

Micro-switches. Pye Ltd., Otehall Works, Station Road, Burgess Hill, Sussex. An 8-page folder gives details of a new range of micro-switches having a common movement with different actuators.

Electrical indicating meters. Greibach Instruments Corp., Metuchen, New Jersey, U.S.A. An 8-page brochure describes a wide range of ammeters and voltmeters for field, factory and laboratory use.

X-ray spectrograph chart. North American Philips Co., Inc., 750 South Fulton Avenue, Mount Vernon, New York, U.S.A. A new revised 17½ × 22½ in. X-ray spectrograph chart showing characteristic secondary X-ray beams for elements from magnesium to californium is offered gratis by this firm.

Beckman spectrophotometers. Baird and Tatlock (London) Ltd., Chadwell Heath, Essex. An illustrated 4-page leaflet announces the comprehensive sales facilities for Beckman spectrophotometers and other allied instruments which this firm is now able to offer.

Aluminium casting alloy. Alar Ltd., 3 Albemarle Street, London, W.1. A data sheet gives particulars of the pressure diecasting alloy LM24 which was introduced into the revised BS. 1490.

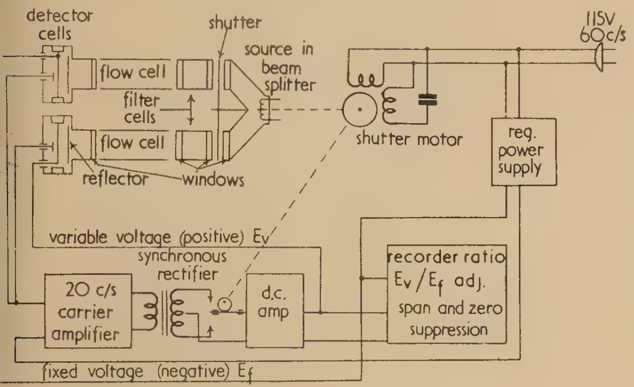
New instruments, materials and tools

e Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved oducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

fra-red gas analyser. Applied Physics Corporation, 362 West Colorado Street, Pasadena 1, California, U.S.A.

ne model 70 infra-red analyser is an instrument for the ntinuous analysing of flowing gas samples. Radiation from n infra-red source is split into two parallel paths and chopped 20 c/s by a rotating shutter. The radiation in each path sses through a filter cell and sample cell to a detector. The urce consists of a Nichrome spiral heated to approximately 5° C by current from a regulating transformer. It is housed a finned box attached to an aluminium alloy block which ts as beam splitter. The two exit ports of the beam splitter e closed by silver chloride windows and an Ascarite capsule the aluminium block removes carbon dioxide and water pour from the air in the beam splitter and source unit. he rotating shutter has opposite quadrants made of metal, that both beams are chopped simultaneously. The shutter aft carries a pair of cam-driven relay contacts which nction as a synchronous rectifier for the electronic circuits.

The bodies of the filter and sample tubes, and the radiation etectors, are made of heavy wall, stainless steel tubing. hese assemblies are rigidly attached together by concentric amp rings having a wedging action, so that they can be asily taken apart for cleaning and reassembled in perfect linement. The inner surfaces are polished so that radiation roceeds from the source to the detectors by multiple reflexion om the walls. The filter cells and the detectors have indows of rock salt, fluorite or similar material cemented the bodies and held in place by clamp rings so that the ment is in compression. They also have stainless steel alves with Teflon packing for use in filling. These assemblies tain their filling gases unchanged for a long period of time. he sample cells do not have windows, but are sealed to the djacent filter cell and detector body by means of O-rings.



Schematic diagram of infra-red gas analyser

Each detector consists of a gas-filled chamber which is ivided in two parts by the tantalum diaphragm of a conenser microphone. The two parts of the chamber are onnected by a slow leak so as to equalize static pressures. he chopped radiation absorbed in the front part of the amber produces a cylic pressure fluctuation in the filling as to which the microphone responds. The aluminium alloy lock which supports the detectors has distributed heating elements and a thermal regulator to keep the microphone temperature constant. The outputs of the two microphones are added and applied to an amplifier. One of the microphones (in the analyser path) is polarized with a constant potential. The other (in the reference path) is polarized with a variable d.c. potential derived from the output of the amplifier. The amplifier therefore adjusts the variable polarizing voltage so that the sum of the microphone outputs is zero. The amplifier output is therefore proportional to the absorption in the sample path.

The radiation detector is sensitive only in the spectral region where the filling gas has absorption bands. It will therefore show large changes in output when the concentration of the *same* gas in the sample tube changes. Other gases in the sample tube will produce an effect only if they have absorption bands which overlap those of the detector filling. It is possible to blank out the spectral regions in which overlapping of absorption bands occurs by filling the filter cells with the interfering gases.

It is stated that the analyser will detect traces of absorbing gas of the order of one part in 10^6 in the presence of non-absorbing gases. When two absorbing gases are present, discrimination ratios against the interfering component are obtained ranging from several hundred in favourable cases to 25 when overlapping of absorption bands occurs.

Point source stroboscopic lamp. Dawe Instruments Ltd., 99 Uxbridge Road, London, W.5.

A new accessory, known as the type 1202C/1 point-source stroboscopic lamp unit, has been designed for use with the type 1202C Strobotorch. Using a Mazda type FA5 lamp, the unit provides a point-source of stroboscopic light over the range 120–10 000 flashes per minute. The design of the unit permits the use of either a reflector or lens system, for projection and microscopy.

The type 1202C/1 point-source stroboscopic lamp unit (left) for use with the standard Strobotorch lamp (right)

The output of the unit is within the range 0·1–2·35 J (W × s), depending on the flash-rate. The figure shows the new point-source lamp unit and connecting box at the left, with the normal Strobotorch lamp unit at the right. The normal lamp is rendered inoperative, but its speed control is used to control the flash rate of the point-source lamp.

The power unit is shown at the centre. The independent mounting of the new lamp unit enables it to be used with optical systems of any required focal length, since the mounting provides free access from three sides.

"Synchro" test equipment. Muirhead and Co. Ltd., Beckenham, Kent.

A range of precision "synchro" test equipment is made for tests of electrical accuracy and residual voltage on "synchros." In addition, facilities are provided for adjusting to zero, transformation ratio measurements and current and power measurements. The test equipment comprises:

(i) a delta network of precision resistors and switches to give any electrical angle in 10° steps;
(ii) a phase-sensitive detector with high input impedance and high gain. This has an automatic gain control characteristic to eliminate the need for frequent gain control adjustment;
(iii) a comparator type valve voltmeter with built-in filter for fundamental component and total residual voltage measurement;
(iv) a standard transmitter complete with positioning fixture for tests on control transformers and differentials;
(v) a mechanical positioning fixture accurate to 30″ and with a scale reading the "synchro" error directly without the use of lenses;
(vi) a fork-controlled oscillator with amplifier which supplies power to the "synchro" under test at an accurate frequency of 400 c/s.

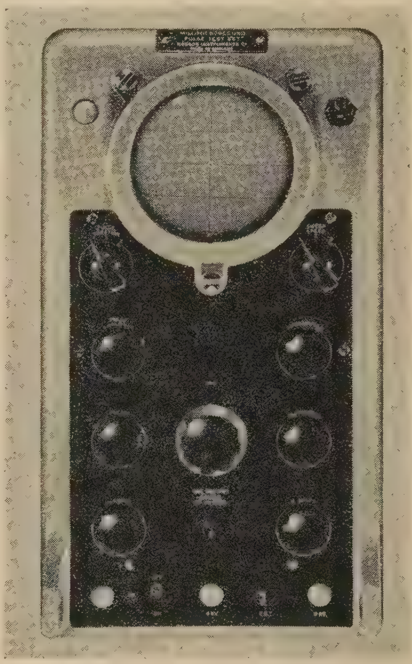
Image converter and dissector tubes for use in high-speed photography. Mullard Ltd., Mullard House, Torrington Place, London, W.C.1.

Image converter tubes have an important application as high speed electronic shutters. Shuttering action is obtained by switching on the tube for the required period by applying a voltage pulse. In the case of a diode tube such as the type ME1200, this requires a peak value of about 6 kV. Lower shuttering voltages are possible with triode tubes such as the type ME1201 which can be switched on by a grid voltage of 2 to 3 kV. Voltage pulses for operating such tubes at exposures down to about 10^{-7} s can be generated by hydrogen thyratrons. For shorter exposures, down to 10^{-9} s, a coaxial line pulse generator may be used, and a special tube type ME1203 has been designed for use with a 13 Ω line.

Although image converter tubes can give satisfactory *single* exposures down to 10^{-9} s, the most efficient fluorescent screens have an afterglow of 2×10^{-5} s, which limits the repetition rate for multiple shots and causes blurring if high speed film transport is used. To make possible the recording of up to one hundred frames on a single negative, image dissector tubes have been developed. The photo-cathode of such a tube is active only in an array of "mark" areas separated by non-emitting "spaces," so that with uniform illumination on the cathode only the "mark" areas are reproduced on the fluorescent screen. During an exposure, electromagnetic or electrostatic scanning deflects the "marks" uniformly across the "spaces" at the screen, the tube being switched off before overlapping occurs. The result is a composite negative which can be analysed into a series of frames each representing a single time element. The analysis can be made either by viewing through a suitable transparency or by "playing back" through a decoding tube. One type of image dissector tub is the "dot cathode" tube, which has a cathode active in a array of dots 0·001 in. square and 0·009 in. apart. Scannin is effected electromagnetically. Another type is sensitive i a series of concentric rings separated by spaces. Scanning i then effected by varying the anode voltage on the tube. I each case, a similar kind of tube is used for decoding and b varying the scanning voltage a particular frame can be picke out of the composite picture.

Millimicrosecond pulse generator and display unit. Cosso Instruments Ltd., Cossor House, Highbury Grove London, N.5.

This instrument shown in the figure has been designed t test passive and active networks by pulse technique an consists of an adjustable pulse source, a display oscillograp and power units. A free-running blocking oscillator an shaping circuits generate pulses of approximately 250 V peak amplitude and of substantially sine² shape and of width 5, 20 or 50 mμs. The oscillator also provides the sawtooth voltage for the oscillograph time base so that the transmitter pulse is always presented at the start of the cathode-ray tube traverse and automatically locked. If a passive network such as a cable (which may vary in length from about 18 in. to 200 yd) is connected to the pulse source then, if mis-matched, reflexions of the transmitter pulse will appear on the traverse as echoes. From the characteristics of the echoes information such as the location and magnitude of a discontinuity is readily obtainable. The cable impedance and electrical length, its losses and phase response, can also readily be determined. The technique can be applied to both transmission and delay cables and, if both ends of the line are available, the characteristics of the transmitted pulse as seen at the far end of the network can be examined. This is useful for the study of wide-band amplifiers, particularly of the distributed type.



Millimicrosecond pulse test set

tatic electrodynamometer meters. Rawson Electrical Instrument Co., 110 Potter Street, Cambridge 42, Massachusetts, U.S.A.

e coils in this range of meters are subdivided and balanced h respect to each other so that external fields have no ect. It is claimed that this makes it unnecessary to use gnetic shielding, and therefore eddy current and hysteresis ses are eliminated. It is stated that there are no reversal ors on d.c. readings and that the calibration is accurate frequencies up to at least 1 kc/s.

Milliammeters are available in ranges from 10 mA (internal pedance 1400 Ω + 80 mH) to 100 mA (internal impedance Ω + 0·8 mH). Multi-range voltmeters are made with nges from 10 to 1200 V and with resistances depending on range from 10 Ω/V to 100 Ω/V. The wattmeters cover nges from 1 to 200 W at voltages from 50 to 600 V.

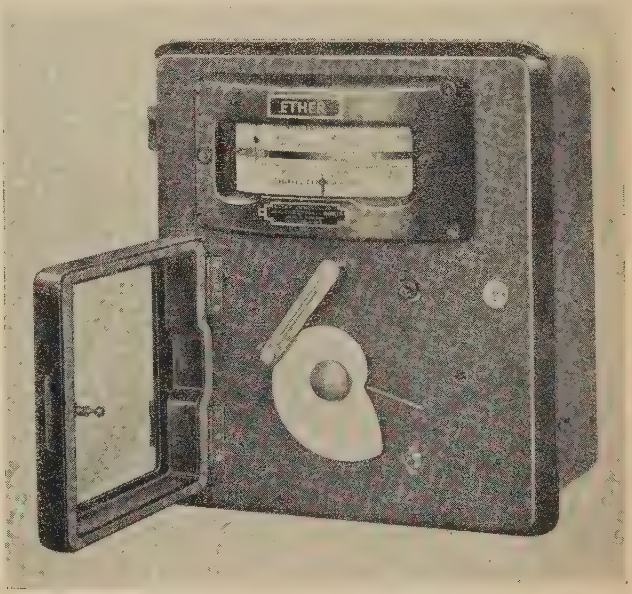
cuum switch. Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex.

e VS. 5 switch, illustrated in the figure, is an auxiliary unit use with an ionization gauge of the Philips type. It ovides sensitive switching facilities in the range 10^{-3} to $^{-5}$ mm of mercury without appreciably affecting the gauge libration. The device consists of an electronic relay inserted tween the Philips gauge head and its control unit. At a e-set pressure, the relay operates changeover contacts to tuate process controls or warning devices. This is accomished by passing the discharge current from the gauge head rough a pre-set resistance; when a potential difference of out 60 V is developed across the resistor, a voltage disiminator circuit is triggered which actuates a magnetic st Office relay. In normal operation, the relay will change ver each time the system pressure passes through the pressure tting of the instrument, "above" and "below" indicator mps showing the state of the system in relation to the strument setting. A latching facility is provided so that if e pressure rises above the instrument setting and subquently falls, the relay remains energized until re-set. This useful for warning devices which must operate on omentary pressure increases which might not be noticed y the process observer.

Vacuum switch with Philips type gauge head and associated control unit

rogramme temperature controller. Ether Ltd., Tyburn Road, Erdington, Birmingham 24.

he Transitrol controller employs a direct deflexion galvanoeter as the detecting instrument. This is used in conjunction with a thermocouple or resistance thermometer for temperature control, but the device can equally well be applied to any process where the signal can be converted into a direct current. The galvanometer is fitted with an Alcomax II magnet, a high resistance coil, precision-ground hardened pivots and spring-loaded polished sapphire jewels, thus ensuring high accuracy and stability under severe operating conditions. Calibrations are available for use with all types of thermocouples or other temperature sensitive elements. The instrument is compensated for cold-junction variation, and internal resistance changes due to the temperature-resistance coefficient of the copper moving coil. An adjustable rheostat is provided for final calibration according to the length of the compensating lead used on a particular installation. The controlling element is a photosensitive transistor which, with a lens and low-intensity light source, is attached to the index control pointer. When the transistor receives full illumination a relay is energized to control external circuits. The temperature-indicating pointer is fitted with a flag, capable of passing freely between the light-source and the transistor. When the desired temperature is attained the light source is cut off from the transistor, thus de-energising the relay and switching off the heating current. The design of the optical system ensures that only a small movement of the pointer is needed to operate the relay, thus giving close control. Signal lights indicate mains on/off and control on/off. An electric motor below the control unit drives the cam on the front of the instrument at a selected speed. In contact with this cam is the control arm, which is connected by a pair of precision-cut bevel gears to the red index control pointer of the indicating unit. The face of the cam is graduated in time and temperature, the time marks being radial and the temperature marks being circles. This makes it easy to cut a cam to suit any particular time-temperature programme. A gear train enables eight speeds to be obtained by changing only one gear of the train. The power consumption of the instrument is 2 VA, and it is capable of controlling 5 A at 230 V a.c. with a non-inductive load.



Temperature programme controller

Notes and comments

Paul Instrument Fund Grants

The Paul Instrument Fund Committee, composed of representatives of The Royal Society, The Physical Society, The Institute of Physics and The Institution of Electrical Engineers, was set up in 1945 "to receive applications from British subjects who are research workers in Great Britain for grants for the design, construction and maintenance of novel, unusual or much-improved types of physical instruments and apparatus for investigations in pure or applied physical science."

Grants have just been made from this fund to Prof. R. V. Jones, and Dr. A. H. S. Holbourn (University of Aberdeen) for continuation of the development of an engine for ruling diffraction gratings in which, in order to avoid the difficulty of making an almost perfect screw, use is made of light waves to determine the grating space.

A grant has also been made to Prof. S. Devons (University of Manchester) for an investigation of the proposed optical system of a new type of reflecting camera incorporating a correcting lens and furnishing increased speed and field of view. This camera could be used in an investigation of the structure of weak extended sources of light in interstellar space of the Milky Way.

Instruments used in industrial hygiene

A conference on instruments used in industrial hygiene organized by the British Occupational Hygiene Society, will be held in London on 16 and 17 April, 1957. Introductory papers on statistical and clinical aspects of the subject will be read by Mr. R. C. Tomlinson, of the National Coal Board, and by Dr. P. Lawther, of the M.R.C. Group for Research on Atmospheric Pollution. Other papers will deal with instruments used for promoting safety in mines, with radiological instruments, and with field tests for toxic gases. Mr. Isbell, of Hilger & Watts, Ltd., will speak on spectro-photometers and colorimeters. The conference will conclude with two papers by authors from the Atomic Energy Research Establishment dealing with environmental measurements and with instruments for the clinician. It is open to non-members of the British Occupational Hygiene Society on payment of a registration fee of one guinea which entitles them to receive a copy of the proceedings. Those who wish to attend should write to the Honorary Scientific Secretary, Dr. D. Turner, M.R.C. Laboratories, Holly Hill, Hampstead, N.W.3.

Small Instrument Exhibitions

It has become quite common to invite scientific instrument manufacturers to display some of their products in connection with meetings or conferences organized by various groups up and down the country. It is not, however, always realized how time consuming the preparation, display and dismantling of such exhibits can be, and how difficult it is for firms to spare members of their staff to do this, much a they might welcome the opportunity of showing their good There are a number of points which the organizers of suc exhibitions should bear in mind, in order to help the exhi bitors; some of them although obvious, are, we regret t say, often completely overlooked—for example, reasonabl easy access to the exhibition room for heavy packing case and a place to pack and unpack.

The Scientific Instrument Manufacturers Association d Great Britain have issued an admirable little pamphle entitled "Code of practice for the organization of sma instrument exhibitions" which we commend to all who have or are likely to have anything to do with this type of exhibitio If they follow its wise counsels, we know from experienc that they will not only be helping the exhibitors but savin themselves a good deal of trouble during the "heat an burden of *the* day." Copies of the pamphlet may be obtaine gratis from the Secretary of the Association, at SIMA House 20 Queen Ann Street, London, W.1.

Gamma-ray source capsules for radiography

An eight-page British Standard has just been publishe with the title *Gamma-ray source capsules for radiograph* (B.S. 2783: 1956). This standard has been evolved in clos collaboration with the Atomic Energy Research Establish ment and the Radiochemical Centre. It deals with two design of cylindrical capsules, about 1 in. long, for the convenien holding of radioisotopes other than radon, and for rad respectively.

The specification gives fully dimensioned diagrams illus trating the two types of capsules, and in the case of capsule for radioisotopes other than radon a series of dimensions i given which provides for the use of sources from 2 × 3 mm or smaller, up to 6 × 6 mm. Whilst the standard is primaril a dimensional one, some notes are included as to suitabl alloys for the manufacture of the two types of capsules.

Copies of this British Standard may be obtained from th British Standards Institution, 2 Park Street, London, W.1 Price 2*s*. 6*d*.

British Journal of Applied Physics

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Pre-breakdown conduction between electrodes in continuously-pumped vacuu systems. By W. K. Mansfield and R. L. Fortescue.

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The lives of electron microscope filaments. By R. N. Bloomer.

NOTES AND NEWS

New books — Notes and comments

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A survey of image storage tubes*

By H. G. Lubszynski, Dr.Ing., F.Inst.P., Research Laboratory of Electric and Musical Industries Ltd., Hayes, Middlesex

There are two types of half-tone storage tubes. They operate either with charge restoration or charge modulation. After stating the requirements such tubes must fulfil for various applications, a number of tubes, representative of their classes, are described. The factors limiting their performance are discussed. In general, writing speeds of $0 \cdot 1$ μs/picture element can be achieved, while reading times may vary from a fraction of a second to many hours. Limiting resolutions range from 400 to 2000 lines across the target. Erasure times are still somewhat too high for use in ordinary television. Calculations indicate that improved performance and sensitivity may be obtained in a photoconductive storage tube by incorporation of an electron multiplier. A special type of charge modulation tube is the direct viewing tube which allows observation of the stored picture directly on a fluorescent screen in the tube. Finally, a number of applications of such tubes are described.

INTRODUCTION

ıe electronic storage tube is a device which has been veloped over the last few years. It was stimulated largely the experience gained in the development of television mera tubes operating on the charge storage principle. The velopment has been very rapid and there is now a large mber of different types of tubes in existence. A survey ll be given, classifying these tubes according to their erating principles, describing a few samples representative their groups together with a comparison of their per- rmance. Some applications, and some problems of design ll be discussed. We shall be concerned with image storage bes only, e.g. devices capable of storing a half-tone picture rectly. Generally, the information contained in a half-tone cture is written into the storage tube in the form of a charge age on an insulating target and, at a later time, read out d displayed on a cathode-ray tube. Digital storage tubes ll be excluded because they need an intermediate encoding d decoding device to store and reproduce the information ntained in a half-tone picture.

GENERAL

Image storage tubes can be divided largely into two tegories, those which are operating with charge restoration d those in which charge modulation is used.

The former depend for their operation on storing the formation in the form of relatively large charges on an sulating target. These charges are gradually restored by the ading beam over a number of scans to give the reading gnal output. The reading time depends then, of course, on e amount of charge stored in the first place and on the nount taken off in each reading scan. The latter must be rge enough to provide an adequate signal/noise ratio.

In the second kind of tube, the information is again stored form of charges, but these charges are made to modulate flow of current coming from a separate source which, at ast ideally, does not in turn obliterate the stored charges the process. Such tubes should basically allow much nger reading times. In practice, other effects occur which t limits to the reading time. One type of charge modulation be is the direct viewing tube, where the stored picture can observed on a fluorescent screen in the storage tube itself.

There is a third type of tube which is a variation of the charge restoration tube. This is the photoconductive tube. The charges are stored on the target by photoconduction. The signal is generated by a restoring beam but the photoconductive lag effect is used to replenish, to a certain degree, the charges consumed in signal generation. Thus the reading time is increased.

The requirements these tubes must fulfil depend on their applications. For example, in some cases the information must be written into the tube in a short time but must be capable of being read over an extended period. In other cases it is essential to keep the stored information intact over a period of time, after which it must be read and erased quickly. In yet other applications it is necessary to write and read simultaneously so as to be able to add new information continuously.

The general requirements for all tubes are good resolution, signal/noise ratio, and a desired tonal gradation or transfer characteristic. The writing may be done by means of an electron beam or optically by causing photoemission or photoconduction. Where an electron beam is used, negative charges may be deposited directly. If the beam electrons are fast, and the secondary emission ratio at the target is greater than one, positive charges may be deposited. On the other hand, the electron beam may be used to induce conductivity in an otherwise insulating target and thus produce charges by leakage.

The reading is done by an electron beam. The electron beams for writing or reading may be generated by an electron gun or by a flying light spot scanning an extended photocathode. It is often necessary to control the erasure rate. This can be done by means of a separate erasing beam or by suitable adjustments of potentials in the tubes or by bias lighting.

CHARGE RESTORATION TUBES

After this short introduction, let us look at some tubes, beginning with charge restoration tubes.

Storage Orthicon. The first is the storage Orthicon described by Forgue.(1) It differs from a normal Orthicon through having a special thin target. Later, a similar tube was developed at Electric and Musical Industries Ltd. in England. It is a thin target C.P.S. Emitron, known as the VCRX343. Fig. 1 shows a diagram of a C.P.S. Emitron.(2) The cylindrical glass envelope has a flat window at one end. On the inside of the window a thin transparent sheet of mica or glass of thickness 0·0002–0·0003 in. is arranged. One side of it is coated with a semi-transparent conducting layer, the signal plate. On the opposite side, facing the electron gun, a mosaic is formed which consists of a large number of mutually insulated photoemissive elements which are capacitatively coupled to the common signal plate. At the other end of the tube is an electron gun. The electron beam generated by the gun is focused by a solenoid coil and scanned across the target by two pairs of scanning coils. A short distance in front of the target an ion trap mesh is arranged.

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* Based on a lecture delivered to a joint meeting of the Electronics roup of The Institute of Physics and the Hospital Physicists ssociation in London, on 3 May, 1956.

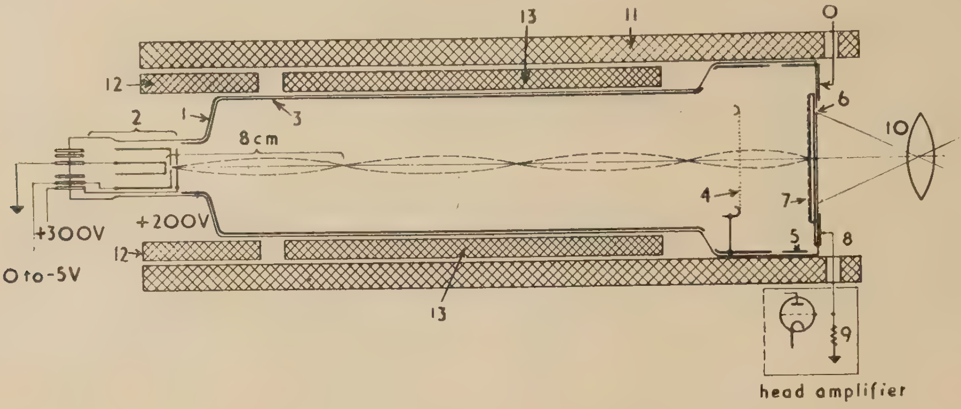

Fig. 1. Diagram of C.P.S. Emitron

(1), glass envelope; (2), electron gun; (3), metallized wall anode; (4), ion trap mesh; (5), decelerator; (6), signal plate; (7), target and mosaic; (8), signal plate contact; (9), signal resistance; (10), lens; (11), focus coil; (12), alinement coils; (13), scanning coils.

An optical picture is focused on the photoemissive mosaic and thereby the target elements become charged positively according to the illumination. The scanning beam restores them in turn to cathode potential and thus produces a pulse in the signal plate circuit which is amplified and constitutes the picture signal.

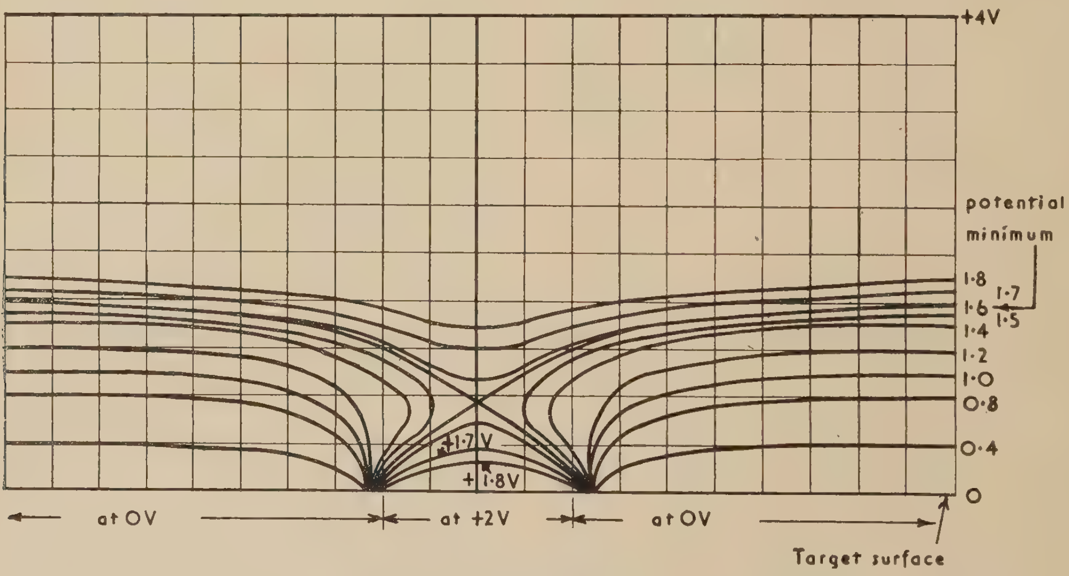

Fig. 2. Potential distribution in front of positive target element

Scale: 0·002 in. = 1 division. Voltage gradient = 80 V/cm.

We have seen that, in a storage tube of the charge restoration type, it is essential to store as large a charge as possibl A limit to the amount of charge stored is set by the voltag excursion of the target elements because excessive potentia changes cause defocusing of the scanning beam and thereb loss of resolution. Moreover, an effect called co-plana biasing tends to reduce the amount of charge which can b stored by an element. The effect is illustrated in Fig. which is a field plot of the potential distribution in front o a small positive area on a target, the rest of which is at zer potential. It can be seen that a potential minimum occur in front of the positive element because of the spread o negative potentials from the neighbouring areas. In the cas shown, the element is at +2 V and the potential at the minimum is 1·6 V. This will prevent a considerable numbe of photoelectrons from leaving the element, thus reducin the sensitivity. The effect is the greater, the smaller th illuminated area. It thus tends to reduce the fine resolutio a picture. Therefore, the target must be made as thin as ssible in order to store a large charge for small voltage ursions.

A further trouble experienced with this tube is the so-called otopulse.(1) The electrons deposited on the target by the toring reading beam cause a pulse giving a signal in the ite direction. On the other hand, any photoelectrons ving the target during the frame time must produce a lse in the black direction. In a normal television picture, s black signal causes no trouble because the total picture ntent does not, normally, fluctuate very much during a me time. Thus the integral of all photopulses is a direct rrent superimposed upon the video signal which slightly ers the black level of the picture. The position is different, wever, when the information to be stored in the tube is a pulsed nature such as, for example, the "blips" of a lar picture. In this case each "blip" written into the tube ises a strong signal in the black direction to be superposed on the output signal. As each "blip" is supposed store enough charge on the target for reading over a large mber of frames, this spurious signal is many times larger an the reading signal. The effect can be mitigated by reading the duration of the "blips" through the use of a ng lag phosphor in the writing cathode-ray tube. It can so be compensated by means of a photomultiplier(3) looking the face of the cathode-ray tube directly and feeding the itput of the multiplier into the amplifier in opposite phase as to cancel out the spurious signal. Where simultaneous iting and reading are not required the photopulse does not atter, of course. In the VCRX343 tube, the target size is × 4 cm, its thickness is 0·000 25 in. and its capacity is 10^4 $\mu\mu$F. With this tube, reading times of 8 s were otained for a 400-line picture and an initial signal/noise tio of 12 dB. With modern amplifiers, this could probably extended to 30 s and 24 dB signal/noise initially. An umination of 0·065 f.c. on the target will then be required, suming a photosensitivity of 20 μA/lm on the mosaic.

As the beam scans over the mosaic, the charges used for storing the elements to cathode potential are abstracted om the beam. The rest of the beam returns up the tube d is thus modulated with the picture signal. The return am can be made to enter an electron multiplier and ampli- d. In that way a high level output signal can be taken om the multiplier which is large compared with the noise the subsequent amplifier. This can, under certain circumnces, improve the signal/noise ratio and thereby the nsitivity and reading time, as compared with a signal plate output. The relative merits of signal plate as against multiplier output are calculated below in the section dealing with the photoconductive storage tube VCRX360. They show that there is no improvement in sensitivity or reading time to be expected from a multiplier output for the VCRX343 under the operating conditions specified above.

A limit is set to the storage time by the landing of positive ions on the target which tend to dilute the charge image. These positive ions are the enemy of the stored charges in all storage tubes and we shall encounter their action in the other tubes to be described.

Graphechon. This is a charge restoration tube in which the writing is not done by photoemission but by bombardment induced conductivity.(4) It is shown in Fig. 3.

The storage member in this tube is a very thin target consisting of an insulating film of magnesium fluoride mounted on a thin aluminium film which also acts as the signal plate. Usually the whole is mounted on a metal mesh for reasons of mechanical strength. If the metal backing is kept at a potential of −50 V, and the front surface of the target is scanned by a reading beam of about 1000 eV energy, the latter surface is charged positively due to loss of secondary electrons until it reaches a potential near that of the collector electrode held at zero potential. Thus a potential difference of 50 V is established across the target. The writing beam, generated by a second gun, is accelerated to 10 keV. It penetrates the metal film and the thickness of the target, causing bombardment induced conductivity in the latter. The writing beam is intensity modulated with the input signal and thus charges are lost by leakage across the target according to this signal. These charges are restored by the reading beam. The signal output is taken from the signal plate. However, the writing signal also appears on the signal plate. In order to separate writing and reading signals, the reading beam is modulated with a carrier frequency which is higher than the highest video signal frequency and the amplifier is tuned to this frequency.

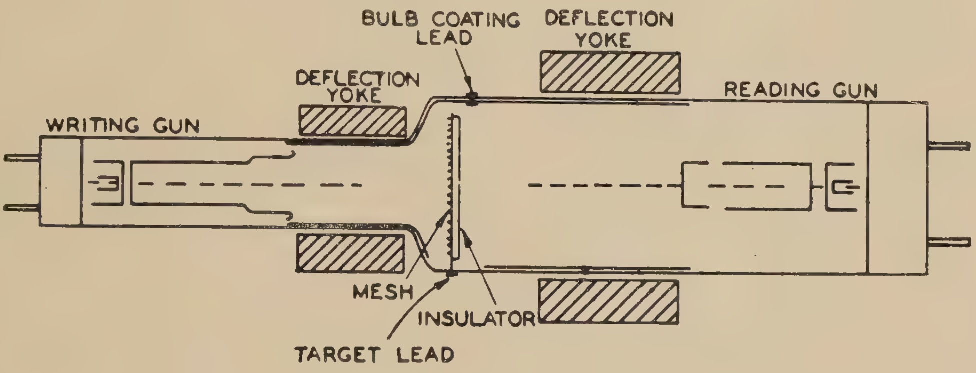

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Fig. 3. Diagram of Graphechon

Writing speeds of 0·1 μs/picture point and reading times up to 40 s have been reported. Erasure takes place by the reading process itself. By increasing the reading beam current the erasure time can be reduced to a few seconds.

Being a high velocity scanning tube, operated in the nonsaturating condition for the secondary electrons, there arise the usual redistribution troubles, resulting in shading signals superimposed upon the picture signal.

Tube VCRX360. The photoconductive storage tube VCRX360 is shown(5) in Fig. 4. It is a low velocity scanning tube of a shape similar to a miniature C.P.S. Emitron, except for the target. This latter consists of a thin evaporated layer of antimony trisulphide approximately $0 \cdot 5\ \mu$ thick which is deposited on a transparent conducting signal plate. This substance is a very good insulator in the dark but becomes conductive upon illumination. In operation, the signal plate is kept at a potential of 4–10 V positive with respect to the cathode of the gun while the front surface of the target is stabilized at approximately cathode potential by the scanning beam. Thus a potential gradient of about 100 kV/cm is established across the target layer. Under illumination, the potential of the scanned surface rises towards that of the signal plate. In scanning, the potential is restored to cathode potential and thus a signal is developed.

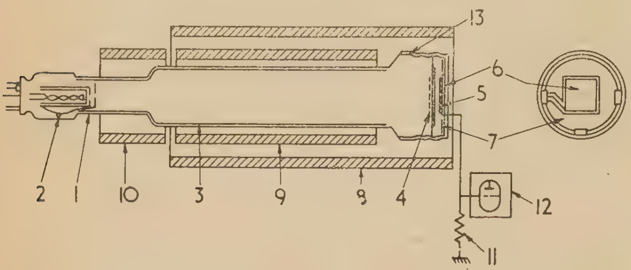

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Fig. 4. Diagram of VCRX360

(1), glass envelope; (2), electron gun; (3), metallized wall anode; (4), ion-trap mesh; (5), target; (6), signal plate; (7), signal plate surround; (8), focus coil; (9), scanning coils; (10), alinement coils; (11), signal resistor; (12), head amplifier; (13), front wall anode.

The storage effect in this tube is of a twofold nature. Owing to the very high capacitance of the target many scans are required to restore it to cathode potential. We call this effect capacitance lag. Moreover, upon interruption of the illumination the photocurrent flowing through the target does not cease immediately but decays over a period of time which may be considerable. The operation of the tube depends to a large degree on this photoconductive lag. The stored information can be read with good signal strength for well over a minute. In some tubes exceptionally long reading times of over 10 min have been observed.

The lag can be considerably reduced by superimposing a steady illumination over the whole of the target. This has two effects. The target is stabilized at a more positive potential where the discharging power of the beam is greater. Thus, capacitance lag is reduced. Also, the photoconductive lag is decreased at increasing illumination. In this way, the reading time can be varied over a range of 3 : 1 in any one tube. Much larger ratios are impracticable because variations of layer thickness and landing velocities of the beam electrons begin to cause shading in the picture at high levels of illumination. A number of ranges of reading times to suit particular requirements can be achieved by changes in layer thickness and processing of the tubes themselves.

The transfer characteristic has a γ-value of $0 \cdot 6$–$0 \cdot 7$ up to levels of illumination on the target of about $0 \cdot 5$ f.c. At very high levels it may become as low as $0 \cdot 35$. The tube is therefore tolerant of great overloads of light. As the γ-value is less than one, the sensitivity of the layer can only be specified in relation to the light intensity. It is of the order of 1000 μA/lm at 10^{-2} f.c. illumination on the target while occasionally 3000 μA/lm have been obtained. Limiting resolutions of 2000 lines have been obtained in the cent of the target. The modulation at 400 lines is 85%. T colour response is approximately panchromatic.

An important feature is the absence of a photopul because the charging is internal to the target layer. Hen the tube can be used for simultaneous writing and readi of pulsed information such as radar displays. Also, there no coplanar biasing. Signal/noise ratios of 36–40 dB a readily obtained. Owing to the low secondary emissi coefficient of antimony trisulphide, the modulation of t return beam with the picture signal is likely to be quite hig

Let us, therefore, compare the relative merits of amplifi as against multiplier, output for such tubes as the VCRX3 and VCRX360. (These calculations are partly based unpublished reports by my colleague Dr. E. L. C. White an myself and by my former colleagues Dr. B. Meltzer and M A. E. Jennings.)

(1) *Amplifier output.* The noise in the signal is generall well below the noise of the 1st stage of the amplifier. Let designate N_a as the ratio of the signal current from the targ to the noise of the amplifier.

The noise power of a frequency corrected amplifier is[(6)]

$$n_a^2 = \frac{16}{3}\pi^2 kTf^3C^2R_N \qquad (1$$

where $k = 1 \cdot 37 \times 10^{-23}$ J/° K is Boltzmann's constan $T = 300°$ K, room temperature; $C = 50 \times 10^{-12}$ F, t capacitance of storage tube output and amplifier inp circuit, $R_N = 120\ \Omega$ the equivalent noise resistance of t first valve of the amplifier.

$$\text{Let} \qquad \frac{16\pi^2}{3}kTC^2R_N = \lambda = 6 \cdot 5 \times 10^{-38}$$

and i_{sa} = signal current output from the signal plate of t storage tube, then the (signal/noise ratio)^2 is

$$N_a^2 = i_{sa}^2/\lambda f^3 \qquad (2$$

(2) *Multiplier output.* The scanning beam leaving the gu must pass through the ion trap mesh on its way to the targe The return beam, modulated by the charges on the targe must again pass through the ion trap mesh. Let the tran mission of the ion trap mesh be t and let the maximu modulation of the beam by peak white signal be m.

If a beam current i_b leaves the gun, the current approachin the target is ti_b. For peak white signal, the current

$$i_{targ.max} = mti_b \qquad (3$$

enters the target. The rest of the current returns, and afte passing the ion trap mesh, enters the multiplier.

$$i_{max.mult} = t^2(1 - m)i_b \qquad (4$$

For no signal charge on the target, the entire curren approaching the target returns and the current reaching th multiplier is

$$i_{o.mult} = t^2 i_b$$

Hence the actual signal current reaching the multiplier fo peak white is the difference between the two,

$$i_{s.max.mult} = mt^2 i_b \qquad (5$$

Let us consider the reading completed at a final signa current into the multiplier which is small compared with th beam current: $i_{s.fin.mult} \ll i_b$; then the total current reachin the multiplier will be near enough the current for no signa

$$i_{fin.mult} \simeq t^2 i_b \qquad (6$$

The noise power carried by an electron current i is

$$n^2 = 2eif \qquad (7)$$

ere $e = 1\cdot6 \times 10^{-19}$ C is the charge of the electron. nce neglecting partition noise, the initial (signal/noise ratio)^2 the multiplier case is, from equations (4), (5) and (7)

$$N^2_{max.mult.} = m^2t^2i_b/(1-m)2ef \qquad (8)$$

d using equations (6) and (7), the final (signal/noise ratio)^2 is

$$N^2_{fin.mult} = i^2_{s.fin.mult}/2eft^2i_b \qquad (9)$$

The noise in the amplifier is "triangular" as compared to "white noise" of the beam in the multiplier case.(7) nce, in order to compare N_a with N_{mult}, the latter must be ighted by an empirical factor of 3 (9 dB). (For a bandlth of a conventional television system of about 3½ Mc/s.) roducing this weighting factor, we get

$$N^2_{max.mult.w} = m^2t^2i_b/(1-m)18ef \qquad (8a)$$

d

$$N^2_{fin.mult.w} = i^2_{s.fin.mult}/18eft^2i_b \qquad (9a)$$

N_{max} and N_{fin} are related, because i_b must be made large ough to ensure the desired initial signal. On the other nd, the noise in equation (9*a*) arises from i_b. Hence, the ater the required initial signal/noise ratio, the greater the al signal current at which reading is considered ternated.

With equations (8*a*) and (9*a*) and letting $18e = 2\cdot88 \times$ $^{-18} = \mu$

$$i^2_{s.fin.mult} = \mu^2 f^2 \frac{1-m}{m^2} N^2_{max.mult.w} \cdot N^2_{fin.mult.w} \qquad (10)$$

We can now compare the amplifier case with the multiplier. r this purpose we specify a desired initial signal/noise ratio d assume the useful reading terminated when the signal/ ise ratio has become unity.

$$N_{fin.mult.w} = N_{fin.a} = 1$$

e can then calculate the required initial and final signal rrents for both, amplifier and multiplier cases, bearing in nd that from the point of signal/noise ratio the signal rrent entering the multiplier is the significant quantity iereas from the point of view of sensitivity it is the current cepted by the target. Thus, calling R the ratio of target rrents, required to give a desired signal/noise ratio,

$$R = \frac{i_{sa}}{i_{targ.mult.w}}$$

d with $i_{targ} = \frac{1}{t} i_{s.mult}$ we get from equations (2), (3), (5))).

$$R_{max} = \frac{\sqrt{\lambda}}{\mu} \frac{m}{1-m} \frac{t\sqrt{f}}{N_{max}} \qquad (11)$$

d

$$R_{fin} = R_{max}\sqrt{(1-m)} \qquad (12)$$

Putting in some numerical values, $t = 0\cdot7$; $f = 3\cdot10^6$ c/s; $_{nax} = 20$ (26 dB); we find that for the VCRX343 tube with low beam modulation of $m = 0\cdot2$; $R_{fin} = 1\cdot2$; $R_{max} =$ 3; in other words, no substantial improvement can be rived from incorporating a multiplier.

Conditions are different, however, for the VCRX360 tube iere the modulation of the return beam may reasonably be pected to be considerably higher because of the low condary emission coefficient of antimony trisulphide. For ample, if $m = 0\cdot6$ we find $R_{max} = 8$; and $R_{fin} = 5\cdot4$ a substantial improvement in both sensitivity and final reading current.

We can calculate the signal currents required with amplifier output from equation (2):

$$i_{sa.max} = 2\cdot7 \times 10^{-8}\ \text{A}; \quad i_{sa.fin} = 1\cdot3 \times 10^{-9}\ \text{A};$$

and using the values of R we find for multiplier output:

$$i_{targ.max} = 3\cdot4 \times 10^{-9}\ \text{A}; \quad i_{targ.fin} = 2\cdot4 \times 10^{-10}\ \text{A}.$$

For amplifier output, a steady illumination of $2\cdot5 \times 10^{-3}$ *f*.c on the target gives a maximum signal/noise ratio of 26 dB. Taking into account the $\gamma = 0\cdot67$ of the target layer, and assuming the modulation to be $m = 0\cdot6$, it can be expected that by incorporation of a multiplier output an improvement of $R^{1/\gamma}_{max} = 24$ in sensitivity will be obtained. Thus the necessary target illumination will be reduced to 10^{-4} f.c.

CHARGE MODULATION TUBES

*Tube VCRX*326. The second part of the survey is devoted to tubes operating with charge modulation. The first to be described is the VCRX326,(5) shown in Fig. 5, in which also an enlarged view of the storage target is shown. It consists of a fine metal mesh on to one side of which an insulating layer of calcium fluoride has been evaporated. The mesh is held at zero potential. Behind the mesh is a metal plate held at a positive potential. At the other end of the tube is a continuous photocathode. Midway between the cathode and target is an accelerating mesh. The whole tube is surrounded by a focus coil. The information is written into the tube by an intensity modulated flying light spot or an optical picture focused on the photocathode. Suppose the mesh and insulating layer are both at zero potential and the photocathode is held at −3 V. Electrons released from the cathode are then landing on the insulator and charge it negatively according to the signal amplitude. When writing is completed, the potential of the cathode is returned to zero and the latter is scanned by a constant intensity flying light spot. The photoelectrons released from the cathode will be able to penetrate the target mesh in the uncharged areas and land on the positive signal plate. The greater the negative charges

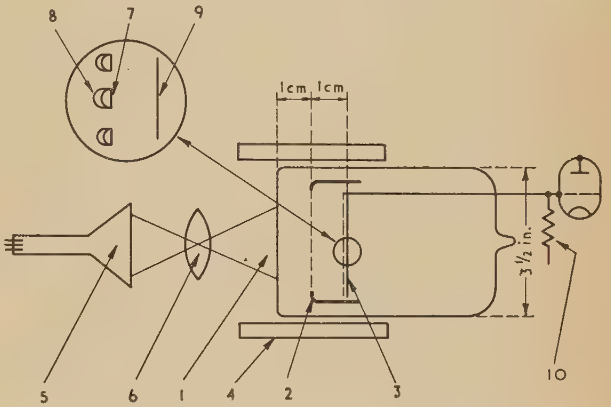

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Fig. 5. Diagram of VCRX326

(1), photoemissive cathode; (2), accelerating mesh; (3), storage target; (4), focus coil; (5), writing and reading cathode-ray tube; (6), lens; (7), storage mesh; (8), insulating coating; (9), backing plate; (10), signal resistor.

on the target, the fewer electrons will be able to penetrate. Thus, the reading beam is modulated with the charges written on the target. None of these electrons can land on the insulator because it is at a negative potential with respect to the photocathode. Thus no wash-out of the stored charges takes place due to the reading operation. There is, however, a destruction of the charges due to positive ions landing on the target which limits the reading time. By keeping the electron velocities below 3 eV throughout, no ionization can take place and reading times of 60 h with an initial signal/noise ratio of 30 dB have been obtained. This is achieved, however, at the expense of resolution which is then only 400 lines limiting. By holding the accelerating mesh at +200 V, the resolution is increased to 800 lines limiting but the reading time is reduced to 15 min.

Owing to the necessity of switching the cathode potential, writing and reading are sequential. For erasure, the photocathode potential is lowered so much that the photoelectrons release more than one secondary electron per primary from the target, thus driving it more positive until it reaches equilibrium with the target mesh. Then the cathode is returned to zero and stabilizes the target at this potential. Erasure can take place at the end of the reading cycle or continuously during fly-back times. The minimum erasure time with alternated reading is 5 s.

Full modulation is obtained when 1/60 lm falls on the target for 1/25 s. With a target size 4 × 4 cm this corresponds to an illumination of 1 f.c. on the target.

Tube VCRX350. By the inclusion of separate writing and reading guns, simultaneous writing and reading was possible in the VCRX350,(5) shown in Fig. 6. The reading section employs a slow electron beam. The storage target consists of a metal mesh coated with an insulating film of calcium fluoride on the side facing away from the reading gun. The mesh is held a few volts positive with respect to the reading cathode. For writing, the fast electron beam from the writing gun is modulated with the picture signals and the beam electrons bombard the insulating surface. There, they release more secondary electrons than primaries and charge the target surface more positively. Under the action of the positive charge pattern on the insulating surface, a variable fraction of the reading beam passes through the holes of the mesh and is collected by the erasure mesh. The rest of the beam returns up the tube and is collected on the reading gun to provide the output signal. By making the erasure mesh negative, a fraction of the reading beam electrons are reflect and strike the insulating surface at low energy. Thereby, t surface is charged more negatively until it finally reaches t potential of the reading gun cathode. At this point no furth reading electrons can penetrate the mesh and the whole the reading beam returns to the gun. Minimum erasure ti was found to be about 3 s, while the maximum reading ti is about 30 min. The reading time is increased by increasi the storage target capacity. On the other hand, in order obtain the same amount of modulation, the charges deposit by the writing beam must also be correspondingly greater a thus the writing speed is reduced. The initial signal/no ratio is about 25 dB. Again, a limit is set to the reading ti by the positive ions which are generated by the writing a reading beams and tend to raise the target potential so th the black level of the signal gradually increases. In order reduce spurious signals from being developed by the fracti of the writing beam which penetrates the mesh and is scann over the collector electrode, an interceptor aperture arranged in front of the gun. This intercepts most of t spurious current but practically none of the reading retu beam. The transfer characteristic is practically linear over range of about 30 dB.

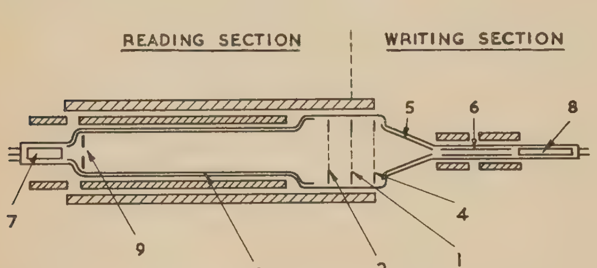

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Fig. 6. Diagram of tube VCRX350

(1), storage mesh: 0–+4 V; (2), ion-trap mesh: 10 V positive to wall anode; (3), wall anode: +400–+500 V; (4), erasure mesh: −5–+1000 V; (5), wall anode: +50 V; (6), wall anode: +50 V; (7), reading gun: cathode 0 V, anode +500–+600 V; (8), writing gun: cathode −1·5–−4 kV, anode +50 V; (9), writing beam interceptor.

The writing speed is about 0·3 μs/picture elemen Resolution in the centre is 1/500 picture diameter.

In this tube there is no photopulse. It is therefore suitab for the simultaneous writing and reading of pulsed inform tion, and is actually being used in this way. Also, the writi speed is high enough to record a standard television pictu When recording a single frame, a signal/noise ratio of 20 was obtained, while integration over three frames gave signal/noise ratio of 30 dB.

Metrechon. We have seen the effect of co-planar biasi in the storage Orthicon. In a similar way, the curre landing on a metal mesh can be controlled by the potenti of a closely spaced plane electrode behind it. The Me rechon(8) shown in Fig. 7 is based on this effect. The tube double-ended. Electrons from the high velocity writing g bombard the insulating glass target. In front of the target mesh is arranged. This is the writing mesh.

On the opposite surface of the glass sheet a metal me film, the reading mesh, is deposited. This side is scanned the slow reading beam. The portion of the reading beam n accepted by the reading mesh returns up the tube and ente the electron multiplier from which the output signal is take

Let the two surfaces of the target as well as writing ar reading meshes be at the same potential at the start. The let the fast writing beam be scanned over the target releasi secondary electrons from it. During this scan, the inform tion is written into the tube as negative pulses on the writi mesh. This negative potential drives a larger or small number of secondaries back on to the element from whic they originate. Thus, the information is stored in form negative charges on the glass film. Owing to the capacitati coupling between the two opposite surfaces, the charg image appears in form of induced charges on the opposi side of the target. These in turn control the amount reading beam electrons which can land on the slightly positi reading mesh. As the charges on the target are negative, reading electrons can land on it to destroy the charge imag Again, however, any positive ions generated by the readi beam are attracted by the negative target and tend to was out the stored charges.

Erasure is carried out by joining the two meshes an bombarding both sides of the target with fast electrons, th driving both sides of the target to mesh potential by seconda ission. A writing speed of 0·3 μs/picture point is reported r this tube. By going to the limits of writing current this ay be increased to 0·1 μs/picture point. 250 lines/diameter n be resolved with 100% modulation, while the modulation r 550 lines is only 10%. Maximum reading time is 10 min, nile with the fastest erasure rate 10% of the original signal left after two scans. Thus a single television frame has en stored reasonably well.

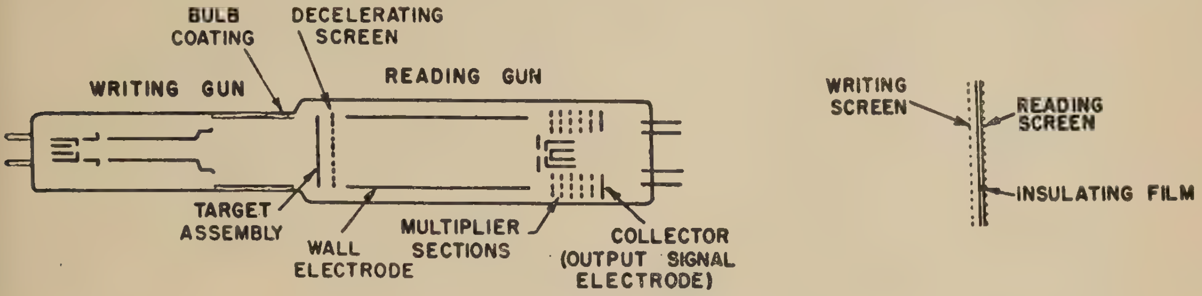

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Fig. 7. Diagram of Metrechon

DIRECT VIEWING TUBE

The survey would not be complete without describing a presentative of the direct viewing storage tubes.(9) It is own diagrammatically in Fig. 8. The tube comprises a orage target, a writing gun, a viewing gun and an erasing n. The writing and erasing guns produce focused scanning eams while the viewing gun produces a flooding beam. The orage target consists of a mesh screen which carries an isulating film on the side facing the guns. The slow erasing eam deposits electrons on the target until its potential is riven to that of the erasing beam cathode which is a few olts negative with respect to the viewing cathode. Thus, no ectrons from the viewing gun can penetrate the mesh. For riting, a fast electron beam from the writing gun is intensity odulated with the signal and bombards the insulating target. here it releases more than one secondary/primary and thus charges the target surface more positively. This allows a number of electrons from the viewing gun to pass through the holes in the mesh. Those which have penetrated are accelerated towards the viewing screen which is kept at +2–10 kV. The erasing beam is depositing electrons on the target, thereby charging the target potential sufficiently negative so as to block the reading beam electrons. A limit to the reading operation is again given by the positive ions which tend to charge the target more positive. The higher the capacity the longer the reading time, as in the VCRX350 tube. Again, this entails a lowering of the writing speed. Resolution obtained so far is about 500 lines limiting. The maximum contrast ratio obtained is 20 dB. A highlight brightness of 500 ft lambert was obtained at 9 kV on a screen of 4 × 4 in. Viewing times of 30 s have been achieved. A half-tone picture can be written in 1/30 s.

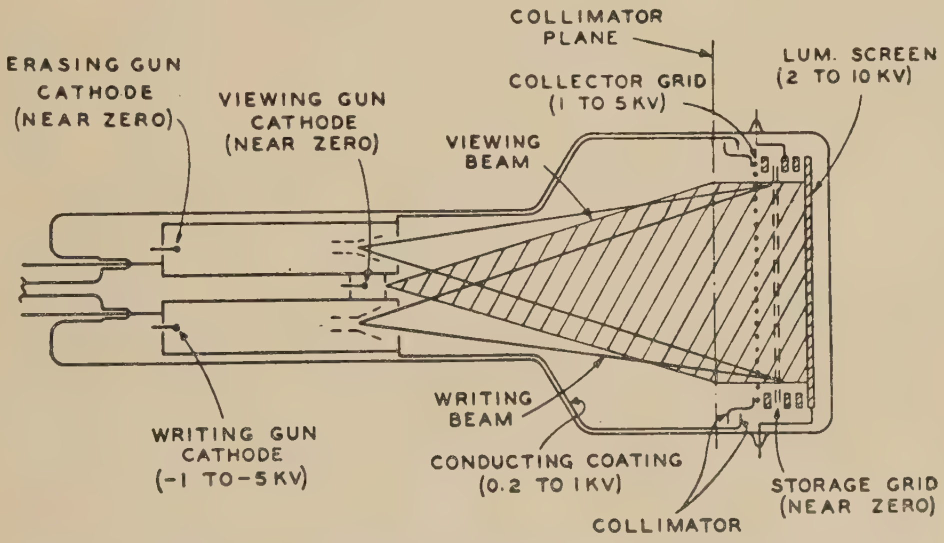
COLLIMATOR PLANE
ERASING GUN CATHODE (NEAR ZERO)
VIEWING GUN CATHODE (NEAR ZERO)
COLLECTOR GRID (1 TO 5 KV)
LUM. SCREEN (2 TO 10 KV)
VIEWING BEAM
WRITING BEAM
WRITING GUN CATHODE (-1 TO -5 KV)
CONDUCTING COATING (0.2 TO 1 KV)
STORAGE GRID (NEAR ZERO)
COLLIMATOR

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Fig. 8. Diagram of direct viewing tube

APPLICATIONS

Let us now consider some applications. Let it be said, before we start, that the simplest form of storage is, of course, the photographic plate. Whether a storage tube is used, or a photographic plate, will depend on a number of circumstances. In many applications such as radar, for example, new information is added continuously to the stored picture. This excludes the use of photography. Also the immediate availability of an electronically stored picture is an essential advantage in many cases. Not least, the sensitivity of modern storage tubes is superior to that of the photographic emulsion.

When a storage tube is to be used we have to decide on the type of tube. To begin with, we have to consider whether the information exists in the form of an optical picture or of a video signal. In the first case, tubes with photoemissive or photoconductive writing will be the obvious choice. Special requirements such as reading time, erasure rate, etc., may make it necessary, however, to convert the picture into a video signal and store it in a tube of the electron beam writing type and vice versa. Where the information exists as a video signal, it may yet be advantageous to display it on the screen of a cathode-ray tube and write it into a photoconductive tube like the VCRX360 tube.

As regards the tubes where the writing is done by means of a scanned intensity-modulated electron beam, it is interesting to note that the reported writing speeds and resolutions resemble each other very closely. Erasure rates are not quite fast enough to be useful for a commercial television system in any of them, but good enough for a number of special applications where, for example, a series of pictures have to be stored in quick succession without the need of fast movements being fully recorded as a continuous sequence.

One of the main advantages to be gained by the use of storage tubes is the improvement in signal/noise ratio of a weak picture by integration. The integrated information is then scanned off and the resulting video signal amplified in an amplifier chain so as to give a bright display with high contrast. Thus, it becomes possible to exchange speed of response against improved signal/noise ratio and contrast.

One of the principal applications of such tubes has, so far, been in a high intensity radar display. In order to depict radar noise and spurious echoes on a plan-position indicator tube, it is necessary to follow its path over a number of rotations of the radar aerial. The use of a long lag fluoride phosphor in the plan-position indicator tube produces a reasonably flicker-free high resolution display. The brightness is, however, so low that the display must be observed in a partially darkened room. By writing the information into a storage tube(5) such as the VCRX360 or VCRX350 and scanning it at television frequency, a high intensity flicker-free picture has been obtained which could be observed in daylight. Moreover, by integrating the information over several scans, the signal from an echo adds up in the same place every time whereas the noise signal occurs at random. Thus the signal/radar noise ratio is greatly improved. By integration in a VCRX350 or VCRX360, echoes have been comfortably observed which were just below the radar noise level. This integration can, however, only be successful in a half-tone storage tube and we have thus a case where a half-tone tube is needed to improve an essentially black and white picture. In this particular application the VCRX360 gave a slightly sharper picture with somewhat better signal/noise ratio while reading times and erasure rate were better in the VCRX350 tube. It is possible, however, that in the future a direct viewing tube will be the simplest solution and reduce the complexity of the gear required.

There are possible applications in fluoroscopy where a short exposure picture may have to be examined in detail. Thus the value of 10^{-4} f.c. estimated for the target illumination on a VCRX360 tube with multiplier output would compare favourably with a screen brightness of $10^{-2} - 10^{-3}$ ft lambert as used in fluoroscopy. Similarly, a photoemissive or photoconductive storage tube like the VCRX343 or VCRX360 with a window which is transparent to ultraviolet,(10) X-ray(11, 12, 13) or infra-red radiation can b installed directly in a television camera and made to stor for prolonged reading, a relatively short exposure pictur Keller and Ploke(13) report that in a photoconductive pick-u tube using a selenium target on an aluminium window, the have obtained a contrast intensification and a sensitivit greater than that obtained with contact photography o X-ray emulsion film. For example, a VCRX360 tube with selenium target was found to give strong signals under ultra violet and X-ray illumination.(14) This application may b useful in cases where the tolerance of biological materia limits the exposure time. Thus, a picture of a hand wit reasonable signal/noise ratio has been obtained with X-ray from a tube operating at 30 kV, 5 mA.

A VCRX350 tube has been used for radiography.(15) A patient, who had been given radioactive tracer material suc as radio-iodine was scanned mechanically by a movin scintillation counter photomultiplier arranged in a coll mating box. The output of the multiplier was written int the VCRX350 tube and a complete picture of the patient radioactivity was displayed on a television screen. I under stand it has since been found possible to record the informa tion directly on sensitive paper by means of a recorder, thu eliminating the storage tube. This is, of course, possibl where slow mechanical scanning can be used. For recordin fast phenomena the storage tube will be required.

Storage tubes have also been used for standards conversio in television; for example, from 625 to 405 lines and *vic versa*. The picture of one standard is written into a storag tube and read out at the other standard. In this case hig writing speed, good resolution and reasonably fast erasur are required. A C.P.S. Emitron would be an ideal tube fo this, as long as the frame frequency is the same in bot systems. Good results have also been obtained with photo conductive tubes of the vidicon type. They are especiall suitable because of the absence of a photopulse.

Recently, Hanson(16) and his co-workers in Mancheste have used a VCRX350 tube in combination with a C.P.S Emitron for the quick examination of the interferenc patterns produced by light replicas of crystal structures fo the purpose of interpretation of X-ray diffraction patterns.

Another application is the transmission of televisio pictures over narrow band channels. Supposing we have a picture which does not change rapidly in time; this can b transmitted slowly over a narrow band link and be written at the other end, into a storage tube. The storage tube i then read at ordinary television frequency and gives a brigh flicker-free display.

On the other hand, a fast transient can be written into a storage tube which can then be scanned off slowly for transmission over a narrow band channel and reconstituted at the other end by another storage tube.

The most remarkable thing, however, in connexion with storage tubes is perhaps the fact that there is now a range of such tubes with good performance available in a numbe of countries and yet the applications are, so far, very few The aim of this paper is therefore to describe the operatio of a number of typical tubes and give some performanc figures so as to open the way for further practical applications

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ORIGINAL CONTRIBUTIONS

Accessories for measuring circular dichroism and rotatory dispersion with a spectrophotometer

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[*Paper first received* 5 *October, and in final form* 15 *November*, 1956]

Cotton effect studies require data on absorption, circular dichroism and optical rotation, and it is convenient to obtain them all with the same instrument. The apparatus now described makes this possible over the wavelength range 3500 to 10 000 Å.

xty years have passed since Cotton published his classical per(1) on circular dichroism and anomalous rotatory spersion, but research in this field still continues. Recent velopments include quantum mechanical treatment, photo-emical applications, and the introduction of photoelectric ethods of measurement. As a contribution to the latter, cessories have been constructed which enable both circular chroism and rotatory dispersion to be determined with a nicam type SP. 500 spectrophotometer. Preliminary notes n these accessories have appeared in *Nature*,(2,3) but since en they have been considerably improved. No structural teration to the instrument is required, but it is necessary to place the caesium-antimony photocell QVA 39, which has a -shaped cathode, by a similar cell (such as the UV V4) with semi-cylindrical cathode. Unfortunately, this photocell nnot be used below 3500 Å, as the plastic cement in the olarizing prisms absorbs strongly at shorter wavelengths. he full range of the caesium-silver oxide photocell VS 39 n be utilized, however.

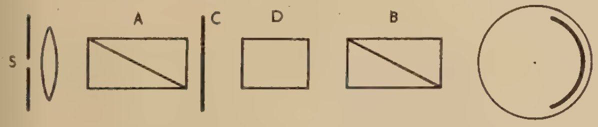

Fig. 1. Arrangement of the optical components

Fig. 1 shows diagrammatically the arrangement of the ptical parts when both accessories are inserted in the instru-ent. The first accessory contains a fixed polarizer *A* and a λ plate *C* which are located between the exit slit *S* of the onochromator and the compartment with the absorption ll *D*. Light from *S* is plane polarized by *A* (vibration rection perpendicular to slit) and circularly polarized by *C* hich can be oriented to transmit right-handed or (by rotation through 90°) left-handed light. The second accessory houses the rotatable analyser *B*, and fits between the cell compartment and the photocell box. Measurements of rotatory dispersion (normal or anomalous) are made by the method of symmetrical angles(4) using *A* and *B* with *C* removed.

CIRCULAR DICHROISM

Constructional details of the circular dichroism attachment are given in Fig. 2. A tube containing the polarizer (a Glazebrook prism 1 × 1 cm aperture) is supported by a brass plate, the lower half of which fits into the cell compartment. The part of the tube projecting in front is accommodated in the passage behind the slit. A detachable holder with a ¼ λ

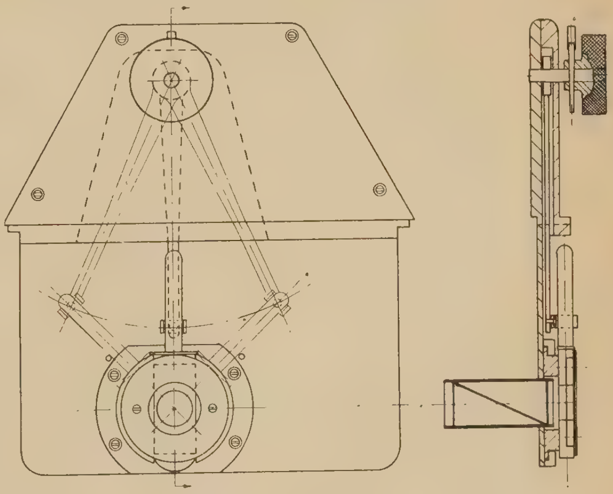

Fig. 2. Circular dichroism attachment

plate,* suitable for the wavelength range being studied, can be rotated between fixed stops by means of an external knob. The rotating mechanism is completely enclosed so that no stray light can enter.

Measurements are made in the following way using the 6 V projection lamp provided with the instrument as light source: (1) Select the wavelength required. (2) Place a glass cell (length l cm) containing solution (concentration c mol./l.) in the light beam. (3) Adjust the slit-width (which should not exceed 0·2 mm) to give 100% transmission (density = 0) for right-handed light. (4) Rotate the $\frac{1}{4}\lambda$ plate through 90°. (5) Adjust the density. The reading on the density scale divided by lc gives the circular dichroism ($\epsilon_l - \epsilon_r$), where ϵ_l and ϵ_r are respectively the molecular extinction coefficients for left-handed and right-handed circularly polarized light.

The apparatus was tested with several chloronitroso-compounds, and the values of circular dichroism obtained agreed to within a few units per cent with those previously determined$^{(5)}$ with a visual spectropolarimeter.

ROTATORY DISPERSION

The analyser unit is shown in Fig. 3. It has two brass plates, one rectangular (8 × 6·5 in.) with a rounded corner, and the other circular (diameter 9 in.). The latter is drilled and tapped to receive the four screws from the photocell box, while the former supplies a new back for the cell compartment, and (protected by a thin layer of cork) is attached to it by four captive screws. Held apart by six distance pieces, the plates carry bearings for a hollow spindle in which the analyser (a Glazebrook prism 1·2 × 1·2 cm aperture) is accommodated. Fixed to this spindle is a metal disk (diameter 8 in.), with a scale reading to 0·2° mounted on its rim. The scale is engraved on white metal and is numbered so that a clockwise rotation brings increasing values past the zero of the vernier, above which the eyepiece is supported. The vernier (reading to 0·01°) is engraved on a white metal strip attached to the fixed circular plate. A long arm (with a locking device) is used to rotate the analyser and scale, an two fine adjustments are provided.

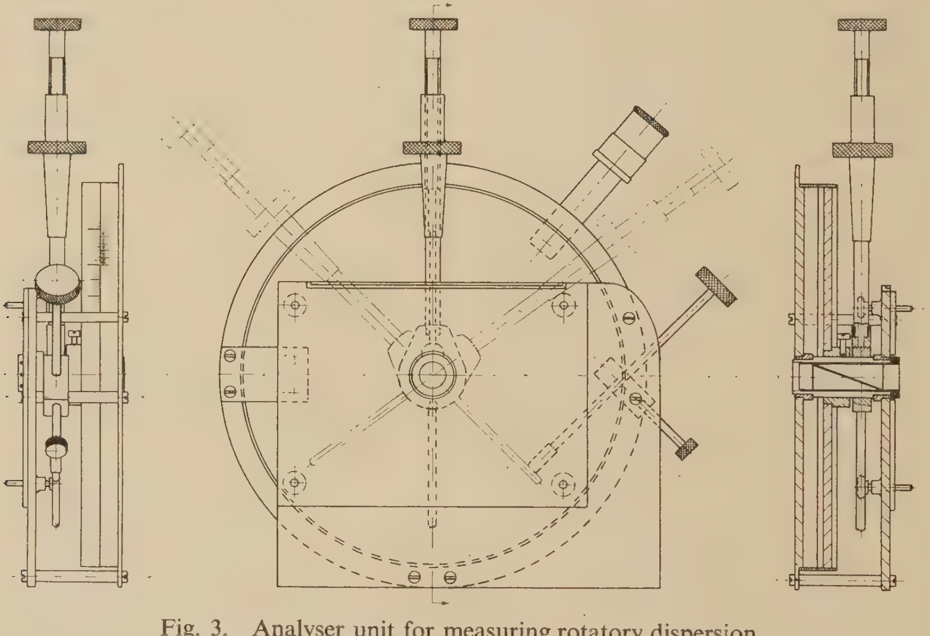

Fig. 3. Analyser unit for measuring rotatory dispersion

When taking a rotation reading for any desired wavelengt the analyser is first adjusted visually (with the photocell bo removed) so that the scale reads approximately 0° when th prisms are crossed. The actual zero is found by the followin procedure: (1) Place the cell containing solvent in the lig beam. (2) Turn the transmission scale to 100. (3) Rota the analyser to a fixed stop (one of the captive screws) to gi a half-shadow angle not exceeding 45°. In practice, 40° found to be convenient so, using the long arm and conic fine adjustment, set the analyser to 320°, i.e. −40 (4) Expose the photocell and adjust the slit-width. (5) Rota the analyser clockwise till balance is restored (using the lon arm and the second fine adjustment). Let the scale read θ then the zero is $\frac{1}{2}(\theta_0 - 40)$. The rotation is determined i the same way with the cell filled with solution. If the sca finally reads θ, the rotation α is given by:

$$\alpha = \tfrac{1}{2}(\theta - 40) - \tfrac{1}{2}(\theta_0 - 40) = \tfrac{1}{2}(\theta - \theta_0)$$

A check experiment was carried out with a solution o cane sugar (26 g in 100 ml.) in a 2 cm cell over the wavelengt range 4000 to 9000 Å. Values of specific rotation were the calculated and compared with those previously published b Lowry and Richards,$^{(6)}$ and by Ingersoll.$^{(7)}$ In the neighbou hood of 6000 Å the values obtained were about 2% too high but for other wavelengths the agreement was within 1%.

The accessories were constructed in our workshop unde the direction of Mr. Robert McCulloch.

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* Obtained commercially for particular wavelengths.

The calibration and use of an air-driven ultracentrifuge

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[*Paper first received* 11 *October, and in final form* 19 *November*, 1956]

The operation of a commonly available (Phywe) type of air-driven ultracentrifuge is discussed, with particular stress upon those experimental aspects which affect the accuracy of derived sedimentation constants. The use of a thermistor in a simple bridge circuit and its calibration by the melting of diphenyl ether to give the actual temperature of the ultracentrifuge cell is described. The derived correction is found to be constant over a considerable range of values of the rotational speed and of hydrogen pressure, but it is strongly dependent upon rotor-thermistor distance. There is good evidence that the thermistor keeps pace with changing rotor temperature. A considerable measure of agreement between the sedimentation constants derived on the basis of the above calibration with those obtained from Spinco values after correction for the adiabatic cooling of the rotor is shown. Attention is drawn to the use of a ball bearing in the base of the rotor which is the probable cause of the unduly large increase in rotor temperature during normal operation.

uring the last decade, the ultracentrifuge has increasingly ecome available for the examination of macromolecular ystems in solution, usually providing information on the omogeneity of a solute as well as giving some indication of s molecular size. Whilst in the general case, sedimentation elocity measurements in the ultracentrifuge cannot alone be sed to obtain molecular weight, nevertheless the sedimentaon constant (or coefficient), obtained under well-defined onditions, is almost as useful a property of a macromolecule n solution. Thus, gross changes in the size, structure and onfiguration of the macromolecule would be expected to ffect the measured sedimentation coefficient significantly; it nust also, however, be conceded that under some circumtances the sedimentation coefficient may become insensitive o molecular size (e.g. in certain linear polymers) or to minor hemical and structural changes, e.g. within a corpuscular nolecule. Such limitations are unavoidable, but, of late, the urprising variability of the constant for a given material as etermined by different workers(1−3) has even further etracted from the usefulness of the sedimentation constant. Vhilst personal differences in technique during the use of a iven type of ultracentrifuge may be partly responsible, the najor part of the discrepancies is probably associated with ne different types of ultracentrifuge used.

Three main types of ultracentrifuge are available: the oil urbine machine due to Svedberg(4) which still remains one f the most precise available, the air-driven machine due argely to Beams and his associates,(5) but more recently nanufactured in Germany by Phywe, and finally the all-lectric machine (by Spinco) due to Pickels(6) which is widely vailable in America and increasingly used in Britain. The ovel and promising magnetically-suspended model described y Beams and co-workers(7) has not, to the author's nowledge, been applied fully as yet to an experimental roblem. Whilst other sources of error are not negligible, seems highly probable that uncertainty about the actual emperature of the test solution in the ultracentrifuge cell uring sedimentation is the most important.(8, 9) Svedberg nd Pedersen (Ref. 4, p. 226) originally suggested observation f the melting of diphenyl ether in the ultracentrifuge cell as means of determining cell temperature unequivocally, and ecil and Ogston(8) described the careful performance of this alibration device on their oil turbine ultracentrifuge. Normally this calibration is applied in the form of a correction o the temperature indicated by a thermo-couple placed close o the rotor surface and, if carried out with proper preautions (see Cecil and Ogston,(8) Biancheria and Kegeles(10)), vould appear a sound procedure, capable of an accuracy of ±0·2° C, or better. However, to maintain this accuracy, rather frequent calibration is required, probably a result of the instability of thermocouple circuits arising from stray thermal e.m.f.'s. Accordingly, in the work to be described, a "thermistor," a resistance body with a high negative coefficient of resistance, incorporated in a simple bridge circuit, was utilized as the temperature indicating element. The behaviour of this device, its calibration by observation of the melting of diphenyl ether, and the results obtained assuming the calibration are discussed in this paper. As is later demonstrated, the thermistor does provide a sensitive and stable temperature-measuring device provided its position with respect to the rotor is carefully controlled. If this and other precautions are taken, the results obtained with the air-driven ultracentrifuge are shown to possess an accuracy comparable with that of the oil turbine and Spinco ultracentrifuges.

EXPERIMENTAL

The basic air-driven ultracentrifuge used was made by Phywe, Gottingen, but, during several years operation, several additions and modifications have been incorporated to increase the precision of the instrument. Thus improved air-pressure control valves and gauges have made for greater constancy of speed so that, during runs of several hours duration, the variation in speed is normally not greater than ±1%, and much smaller for short time intervals. The schlieren optical system was equipped with an accurately adjustable diagonal diaphragm or bar, and index marks on the schlieren records of the motion of a boundary have been provided by drilling suitable holes in a new counterbalancing cell (see Figs. 1 and 7). The precision attainable in measuring boundary displacements has thus been considerably increased. Fig. 2 contains a typical plot of $\log_{10} x$ against time (x being the distance of the boundary from the axis of rotation) for the sedimentation of bovine γ-globulin (shown in Fig. 1) at 43 000 (±300) rev/min in phosphate–sodium chloride buffer at $I = 0 \cdot 2$, pH $= 7 \cdot 8$. The slope of the line ($= \omega^2 s$, ω being angular velocity and s the sedimentation constant) determining the sedimentation constant, can be obtained to better than ±0·5%.

Speed of rotation. Measurement of the speed of rotation was performed by an electromagnetic device described in detail by Eirich and Rideal(11) and shown in outline in the upper part of Fig. 3. The main shaft of the phonic wheel (type A-811-C by Muirhead and Co. Ltd.), which rotates at 10 rev/s, when fed with power at 1000 c/s, is geared down by means of a wormwheel drive to a timing disk, rotating at one hundredth speed. Thus for the whole range of speeds utilized in sedimentation velocity work, the timing of a few revolutions of the timing disk by a good stopwatch can be used to obtain the mean rotational speed of the machine during the small timing interval to within ±0·3%. (The timing of a 40 s interval to ±0·1 s would give this accuracy.)

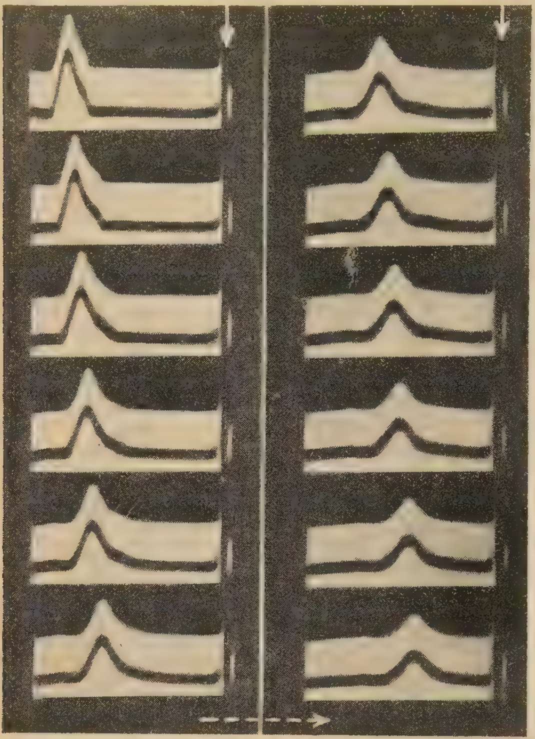

Fig. 1. Sedimentation diagrams for bovine γ-globulin (Armours Fraction *II*) in phosphate–sodium chloride buffer at I = 0·2, pH = 7·8. Rotational speed, 43 000 rev/min. Interval between pictures 8 min. Solid arrows show index marks. Broken arrow shows direction of centrifugal field

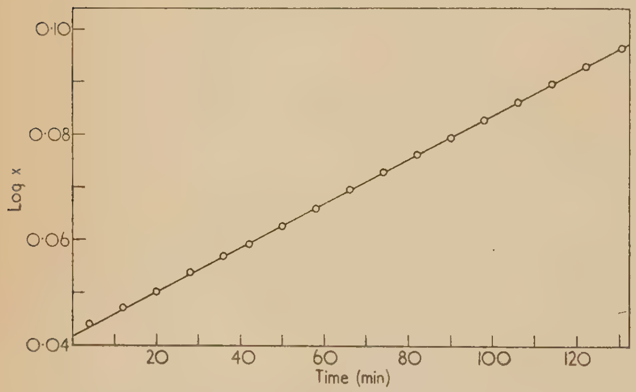

Fig. 2. Plot of log x against time at 43 000 rev/min for the sedimentation of bovine γ-globulin at a concentration of 0·7 g/100 ml. in phosphate–sodium chloride buffer at I = 0·2, pH = 7·8

Providing the construction of the phonic wheel and the gearing ratios can be relied upon (see later), calibration of the method is performed merely by comparing the stopwatch accurately with a standard clock. The soundness of the whole procedure was checked by utilizing the standard frequencies transmitted by the G.P.O. radio station at Rugby. The 1000 c/s signal, received on a standard receiver, was fed into the amplifier and used to drive the phonic wheel, the timing of the latter then being performed by the calibrated stopwatch. From the average of a large number of timings, the calculated frequency agreed with its known value to better than 1 in 10 000, an error which is slightly smaller than the stopwatch error for the timing interval used. This verifies to a high degree the assumed characteristics of the phonic wheel and its gearing system.

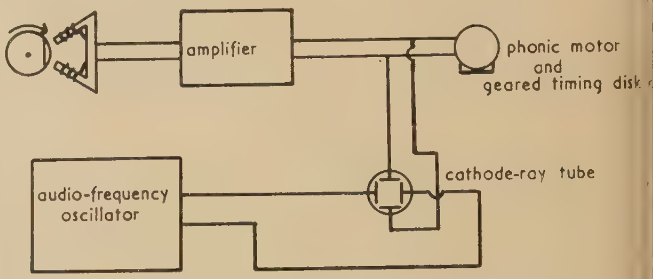
amplifier
phonic motor and geared timing disk
cathode-ray tube
audio-frequency oscillator

Fig. 3. Block diagram illustrating method of measuring rotational speed

The amplifier signal is also fed into a cathode-ray tube which is supplied in addition by a variable frequency from the audio oscillator (Hewlett–Packard); by tuning the audio-signal, stationary Lissajous figures may be obtained which allow an unambiguous choice between the fundamental frequency produced by the disk-generator and its harmonics. However, the value thus obtained is not of high accuracy (unless the oscillator is of high stability and has been calibrated carefully) and it is used chiefly for following changes of speed; especially during the acceleration of the rotor.

TEMPERATURE MEASUREMENT

The temperature measuring thermistor (type M5321/300 by Standard Telephones and Cables, Ltd.) was supported by its minute leads in the gap of a two-pronged Tufnol fork whose position with respect to the rotor surface could be accurately controlled. The copper disk of the actual thermistor element was situated 2·5 cm from the axis of rotation; its distance above the rotor surface, which was not less than 0·06 cm and usually 0·08 cm, was read accurately by a short focus telescope provided with an eyepiece graticule. The thermistor (of resistance at room temperature approx. 5000 Ω) with a 4-dial decade resistance box comprised one arm of the simple bridge circuit shown in Fig. 4 which used a 4½ V dry battery as source of potential. High stability resistors occupied the other arms and the variable resistance shown was used to maintain an approximately constant potential across the bridge, as indicated by the voltmeter *V*. With increasing temperature, the thermistor resistance decreased, and for balance (indicated by galvanometer *G*), the resistance on the decade box had to be increased to give the same total value in the arm. Calibration was performed by placing the thermistor on its Tufnol support and connected into the bridge, with a standard thermometer, into a test tube which was immersed in a water bath whose temperature could be varied between 15° and 30° C. Owing to electrical leakage it was not possible to immerse the thermistor in transformer oil or other insulating fluid, and, before taking e value of the balancing resistance, it was necessary there-re to allow at least ½ h for equilibrium to be reached at any ne temperature. Thus the whole calibration was lengthy and dious. Fig 5 gives a plot of the resistance required for alance against the temperature (indicated by the standard ermometer after appropriate correction), with the dates at hich the different calibrations were performed. It is con-dered that the deviations of individual points from a single mooth calibration curve are within experimental error. The tability of the thermistor when used under proper conditions see makers' instructions), its high negative temperature oefficient of resistance, the simplicity of the resistance neasuring circuit and the ease of making a measurement nake the device eminently suitable for temperature measure-nent, with considerable advantages over the more usual hermocouple. Assuming adequate equilibration, the final ccuracy of a temperature measurement depends largely upon he calibration of the standard thermometer and, assuming ±0·05 for the latter, is probably not worse than ±0·10°.

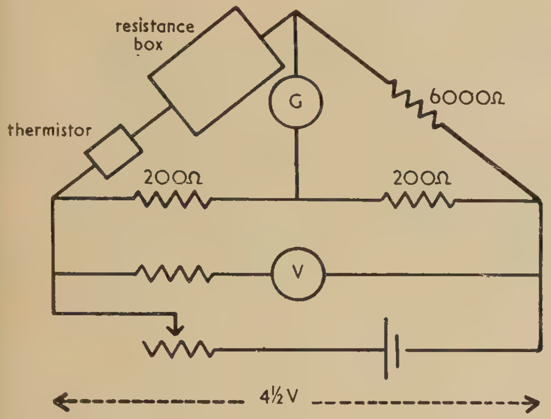

Fig. 4. Thermistor bridge circuit for measuring cell temperature

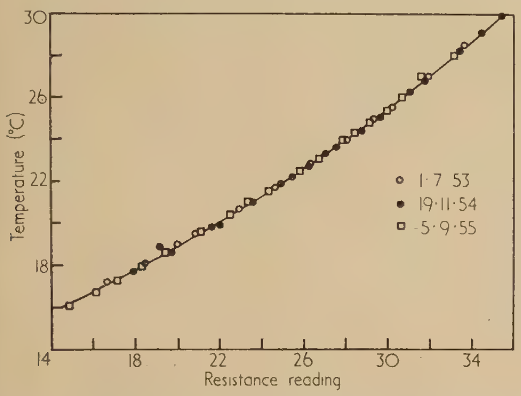

Fig. 5. Thermistor calibration curve. Resistance box value for balance plotted against temperature (°C)

With the rotor at rest and at a temperature close to that f the massive chamber walls, the thermistor accurately ±0·1° C) registers rotor temperature even though it is in oor thermal contact—as was demonstrated by comparing he thermistor-indicated temperature with that obtained mmediately afterwards by placing a thermometer into the ell cavity.

However, under working conditions, the rotor temperature nay be continuously changing, and since a surrounding atmosphere of low pressure hydrogen (or vacuum) is used, it cannot be assumed that the thermistor, separated by approx. 0·05 cm from the rotor surface, accurately records rotor temperature. The difference is made as small as possible by making the distance of separation a minimum and by the use of a thermistor mounted upon an unpolished and highly conducting copper disk. The difference between cell and thermistor temperatures might be even larger, though under normal conditions the temperature gradient across the duralumin rotor would not be expected to be large. With rotor temperatures appreciably above or below the temperature of the surroundings, this gradient may not, however, be negligible and may cause boundary instability. The complications arising from the high linear velocity of the rotor surface (by which kinetic energy could be imparted through the hydrogen molecules to the thermistor) are largely avoided by mounting the thermistor close to the axis of rotation. However, the need for calibration of cell temperature by the use of some indicating substance in the cell is clear and, as yet, only the melting of diphenyl ether has been much used.

Diphenyl ether was distilled under reduced pressure and the fraction distilling at 138° C and 1 cm pressure of mercury was collected. The solid was then stored in thin layers for several weeks in a dessicator over anhydrous calcium chloride and was found to melt at 26·75–26·85° C.[8] This material was introduced in the liquid form into the thoroughly clean and dry ultracentrifuge cell which was then tightly sealed. The melting range above was confirmed by observing the melting of the diphenyl ether in the cell, immersed in a water bath whose temperature was raised by approximately 0·2° C/h.

During routine operation at speeds in excess of 40 000 rev/min, the temperature of the Phywe ultracentrifuge cell rises some 5° C or more during the first hour but more slowly afterwards. Fig. 6 gives the indicated thermistor temperature as a function of time during extended runs at 43 000 rev/min. On the basis of the calibration to be described subsequently, the correction to be applied at the higher temperatures is approximately 0·6° C. During the steep part of the temperature rise, it would seem unsafe to attempt to derive an accurate mean temperature over a short interval of time, and, in practice, measurements over the gradual-rise region only are utilized. Thus the calibration of this portion of the temperature range (24–29° C corresponding with an external temperature of 20 ± 2° C) assumes importance and the melting of diphenyl ether is particularly suitable for its performance.

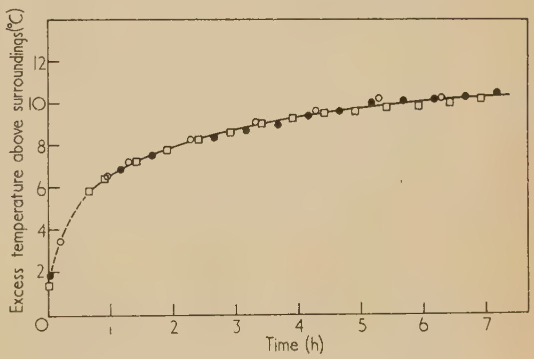

Fig. 6. Plot of excess rotor temperature (above surroundings) against time at 43 000 rev/min. Different symbols denote different runs

Unless otherwise mentioned, runs were carried out normally with respect to hydrogen pressure (7–8 mm of mercury) and acceleration time. The time interval between reaching top speed and the first appearance of melting was largely determined by the speed. At a speed of 46 000 rev/min and an external temperature of 18° C, almost one hour passed before the first signs of liquefaction of the diphenyl ether were observed. With decreasing speed, the heating effect decreased rapidly so that at 37 000 rev/min, in order to observe melting within a reasonable time, it was necessary first to allow the rotor to heat up at higher speed till melting almost occurred. Speed was then reduced and held constant at the lower value. The interface between the clear liquid and the opaque solid was sharp and its position was obtained accurately as a function of time and thermistor-indicated (or apparent) temperature by taking photographs (Fig. 7) at suitable time intervals. Since the melting point of diphenyl ether increases with increase in pressure, rising temperature in the cell is indicated by the occurrence of melting at increasing depths.

Fig. 8(*a*) contains plots of the apparent temperature (from the thermistor) against depth of liquid, as measured directly from the photographic plates, at a speed of 43 000 (±500) rev/min. Each plot corresponds with a given rotor-thermistor distance and may be extrapolated accurately upon the ordinate axis to give the apparent melting point at atmospheric pressure. Defining ΔT as the difference between the apparent and known melting-points of the diphenyl ether, Fig. 8(*b*) gives a plot of ΔT against rotor-thermistor distance. Within experimental error such a plot is a straight line passing through the origin. In most subsequent work a rotor-thermistor distance of 0·8 mm has been utilized, smaller distances being inadvisable owing to rotor swing at low speeds of rotation. Such a distance corresponds with a ΔT value of 0·6 ± 0·05° C and for the conditions used it is clear that real temperatures are obtained from apparent values by the addition of 0·6° C.

Fig. 7. Photographic prints showing melting of diphenyl ether in ultracentrifuge cell at 43 000 rev/min. Interval between pictures 10 min. Broken arrow indicates direction of centrifugal field

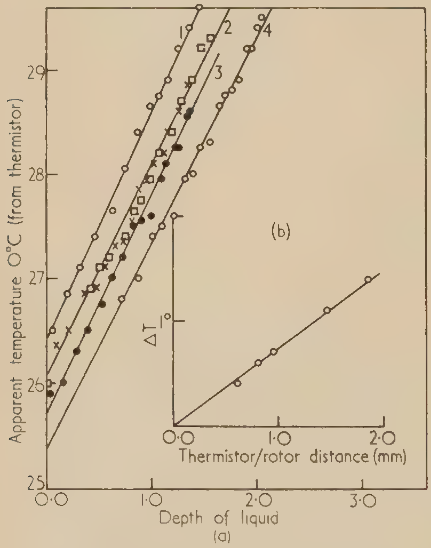

Fig. 8(*a*). Plot of apparent temperature (from thermistor readings) against depth of liquid (in terms of distance on photographic plate) at 43 000 (±500) rev/min and 8 mm of mercury pressure of hydrogen for the following rotor-thermistor distances:

Curve	1	2	3	4
Distance (mm)	0·6	0·95	1·43	1·85

Fig. 8(*b*). Plot of ΔT against thermistor-rotor distance

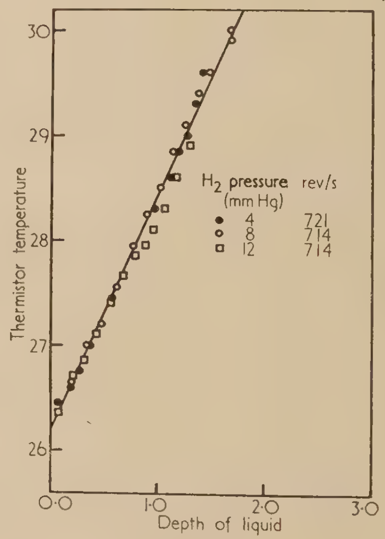

Fig. 9. Plot of apparent temperature against depth of liquid at 43 000 (±500) rev/min for different hydrogen pressures. Thermistor-rotor distance, 0·8 mm

Experimental conditions were now varied and the effect on ΔT values investigated. Fig. 9 thus shows that the variation of hydrogen pressure in the rotor chamber between 4 and 12 mm of mercury, at approximately constant speed, has no detectable effect on the apparent melting-point at atmospheric pressure, nor on the slope of the apparent temperature-liquid depth plots. The very different slopes obtained at different rotational speeds (Fig. 10) result from the effect of rotational speed upon the pressure gradient within the cell, but it is ear that between 620 and 770 rev/sec, ΔT does not change gnificantly. The last conclusion is of considerable impornce for the extreme curves correspond with very different tes of increase of rotor temperature. Thus, at the lowest eed (approx. 620 rev/s) the rotor temperature rose 1·5° C approximately 5 h, whilst at the highest (770 rev/s) the me temperature rise occurred in 50 min. Since the same T value is recorded whether the rotor temperature rises pidly or slowly, it seems clear that the measuring device is eeping pace with the temperature changes over all the nditions investigated. This conclusion is confirmed by lculating the real temperature at different stages of melting om the pressure at the liquid-solid interface and the value f dT/dp ($0{\cdot}02797 \times 10^{-6}$ °K/dyn/cm²) calculated by Bianeria and Kegeles.(10) The liquid density ρ was taken as ·0688 g/cm³, and pressure increases Δp were calculated om $\frac{1}{2}\rho\omega^2(x^2 - x_0^2)$, where x is the distance of the interface om the centre of rotation and x_0 that for the meniscus. he actual temperature was thus given by

$$26{\cdot}8 + 0{\cdot}02797 \times 10^{-6} \,.\, \Delta p$$

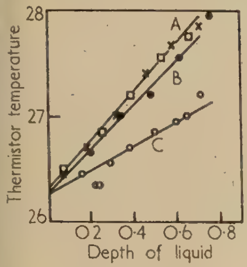

Fig. 10. Plot of apparent temperature against depth of liquid at 8 mm of mercury pressure of hydrogen for different rotational speeds. Thermistor-rotor distance, 0·8 mm

A, 770 rev/s; *B*, 714 rev/s; *C*, 622·5 rev/s.

ig. 11 gives a plot of such temperatures compared with the pparent temperatures from the thermistor. Within experiental error, the two lines are parallel so that the correction o be applied to the thermistor-indicated reading is constant luring the run. Towards the end of the run the temperature ose by less than 1° C per hour whilst initially the rate of its ise was some three times as great; thus under all these conditions it would seem that the thermistor readings follow accurately the temperature changes of the rotor (as was indicated above also).

From these experiments it thus appears, for a given thermistor-rotor distance, that the correction to be applied to the thermistor-indicated temperature is constant for a range of several degrees near the normal melting-point of diphenyl ether. However, it seems clear that when the rotor is operating at a temperature closer to that of the walls of the rotor chamber and its surroundings (which can occur at rotational speeds of 30000 rev/min and lower), then ΔT must be smaller than indicated above and requires further investigation.

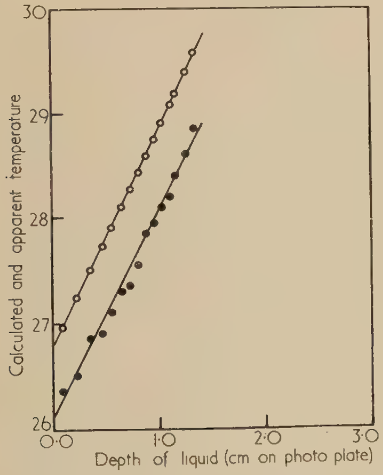

Fig. 11. Plot of apparent temperature (from thermistor) and calculated temperature (from effect of pressure on melting-point) against depth of liquid

●, apparent temperature from thermistor; ○, calculated from dT/dp.

COMPARISON OF SEDIMENTATION CONSTANTS

From comparison of sedimentation constants of well-defined proteins as determined on the Phywe air-driven instrument with those determined by the author on an earlier Sharples ultracentrifuge (see Eirich and Rideal(11)) and by other workers on different (mainly oil-turbine) machines, it had been thought that with the thermistor placed close ($< 0{\cdot}1$ cm) to the rotor surface, that no temperature correction was necessary. Thus for myosin,(12) the s^0_{20} value of 7·1 S is in good agreement with that of Weber(13) and of Snellmann and Erdos,(14) though it was larger than the value (6·7) reported by Mommaerts and Parrish.(15) It seems clear that the latter value is too low as a result of adiabatic cooling of the rotor(16) though other even lower values have very recently been reported (e.g. Laki and Carroll(17)). Similarly the sedimentation constants of arachin, edestin and legumin(18, 19) are in very reasonable agreement with those reported by Pedersen (Ref. 4, p. 406) and by Danielsson(20) for comparable conditions. However, in view of rather general uncertainty in recent years over the question of rotor temperature, the calibration experiments already described were undertaken resulting in the conclusion that a correction of 0·6° C for the usual thermistor position is required; this involves the reduction of previous apparent sedimentation values by the factor 0·986. This factor has been applied in evaluating the sedimentation constants of several well-defined proteins which are given below. In all cases only the gradual-rise temperature region of the results was utilized and detailed comparison with sedimentation constants determined by point-to-point correction for temperature change, showed that it was satisfactory to utilize the weighted mean temperature for total temperature changes of up to 2°. In the main, sedimentation constants were calculated from plots of log x against time, good straight lines being obtained with well-defined slopes, from which the deviations of points in the rapid-rise region were clearly marked (Fig. 2).

During the last few years several workers(1−3) have demonstrated that sedimentation constants of well-defined proteins as determined on Spinco machines may be up to 10% lower than values already published from Uppsala, although agreement with the oil turbine measurements in Oxford is much better. It seems clear, in view of the excellent agreement between the different approaches of Waugh and Yphantis(16) and Kegeles and Biancheria(10) that adiabatic cooling of the spinning rotor must be accepted, which at 60000 rev/min results in raising Spinco sedimentation constants by 2½%. In comparing Phywe results with Spinco values, the latter have accordingly been appropriately corrected.

In a recent paper from the author's laboratory,(21) the sedimentation constant of bovine serum albumin extrapolated to zero concentration (determined on the Phywe ultracentrifuge) was given as 4·51 S. Correcting for the thermistor error, this value becomes 4·45 S in better agreement with mean values from Spinco determinations (4·42 S) and identical with the finally accepted value. However, from sedimentation at a single concentration, Baldwin and Ogston on the oil turbine ultracentrifuge obtain data (as reported by Shulman in Ref. 3) which agree closely with Spinco values uncorrected for adiabatic cooling. Recent work on fumarase has also made possible a detailed comparison of the Phywe machine with a Spinco ultracentrifuge. Two samples of the same 0·2% solution in M/20 phosphate buffer at pH 7·4 were examined in each machine, sedimentation constants of 9·12 S and 9·14 S being obtained in the Phywe machine and 9·13 S and 9·28 S in the other. It should be mentioned that Frieden, Bock and Alberty(22) obtained values some 1½% lower than those reported from this laboratory,(23) but their value for bovine serum albumin is similarly low. The value of Cecil and Ogston,(24) at a single concentration of protein, was even lower, but more recent work(25) has yielded higher values. γ-globulin (Armour's bovine fraction *II*) has been the subject of a similar comparison. The same batch of material was examined in 0·9% sodium chloride solution at a concentration of 0·7 g/100 ml. in both Phywe and Spinco machines. The sedimentation constants were 6·90 S, 6·84 S and 6·84 S from the Phywe machine as against 6·75 S from the Spinco. However, another batch of γ-globulin, at the same concentration in phosphate–sodium chloride buffer at I = 0·2, pH = 7·8, gave a constant of 6·66 S in the Phywe machine. For a human γ-globulin preparation, Cann(26) obtained a regression line of sedimentation constant upon concentration which after correction for adiabatic expansion of the rotor would correspond with a value of 6·49 S at a concentration of 0·7 g/100 ml. On the other hand, Koenig and Pedersen's(27) regression line for bovine γ-globulin would correspond with a sedimentation constant of 7·13 S at the same concentration. While γ-globulin is perhaps far from an ideal reference substance, it seems clear that the Phywe values mainly fall between those from the Spinco and oil-turbine instruments.

With a maximum speed of 50 000 rev/min for the Phywe machine, the sedimentation of insulin in neutral solution represents a practical lower limit; but even so the sedimentation constant obtained in 0·64% solution was 3·24 S (±0·06) which, judging from the somewhat anomalous sedimentation behaviour of insulin(1) is in fair agreement with the value (3·34 ± 0·03 S) of Gutfreund and Ogston(28) for up to 10% solutions, and with the regression line suggested by Miller and Golder(1) (giving 3·36 S in 0·64% solution). Recent uncompleted work(29) from this laboratory using a Spinco machine has tended to confirm the existence of concentration effects and to give a sedimentation constant at 0·64% concentration of 3·33 ± 0·05 S.

In the main, a satisfactory measure of agreement between Phywe and Spinco sedimentation constants is shown; where divergences occur, Spinco values are lower but usually not by more than 2%. On the other hand, Phywe values are considerably lower than those from oil-turbine machines in a number of cases.

DISCUSSION

On the basis of the above comparisons of sedimentation constant, it seems that the Phywe ultracentrifuge is capable of yielding sedimentation constants which are comparable in reliability with those determined on other types of instrument, but this is only achieved at considerable cost. Thus it is usually necessary to ignore experimental observations during the first hour of sedimentation when the temperature is rising rapidly and subsequently an accurate weighted-mean temperature can only be obtained if detailed following of the rotor temperature is possible. The thermistor device described would seem very suitable for this purpose where no other provision has been made. Constancy of speed to ±½% and the use of well-defined index marks are further essentials in achieving accuracy and reproducibility.

The considerable temperature rises demonstrated are somewhat surprising in view of the much smaller effects shown by oil-turbine, Spinco and even other air-driven machines. In the case of oil-turbine and air-driven machines, the use of a low-pressure hydrogen atmosphere is customary so that skin friction is not the source of the temperature rise. The feature of the Phywe machine which is unusual is the use of a small ball race, working at high speed, in the base of the rotor and it seems likely that this is the source of the heat generated. This view has been largely substantiated by O'Donnell(30 who, by removing the ball-race from the rotor and cooling it, has reduced the temperature rise to normal proportions. This solution, or the complete removal of the ball-race (e.g. by the design of a self-balancing rotor) is much to be preferred to attempts to offset the heating by cooling the chamber walls. This could well lead to the development of temperature gradients across the rotor which could seriously disturb sedimentation.

ACKNOWLEDGEMENTS

I am greatly indebted to Mr. L. Saggers who performed the mechanical improvements on the ultracentrifuge, to Mr. J. E. Humpoletz for the design of the thermistor circuit, and to Mr. N. Buttress for his careful performance of a large amount of ultracentrifuge work. I am grateful also to the British Empire Cancer Campaign for financial help during the setting up of the machine.

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An improved micro-electrophoresis electrode assembly for use in micro-biological investigations

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[*Paper first received* 11 *June, and in final form* 9 *November*, 1956]

In the assembly described the electrode liquid (potassium chloride solution) is separated from the suspension under investigation by a sintered glass disk (instead of a plaster plug) and this results in a more permanent and reliable apparatus. The apparatus can be used at higher field strengths than was previously possible, thus enabling low electrophoretic mobility values to be accurately determined. Results obtained are in good agreement with those reported in the literature.

earlier forms of micro-electrophoresis apparatus have n reviewed by Thompson;(1) since this review other difications including those of Rutgers and others,(2) uglas(3) and Hartman and others(4) have been published. h rectangular and cylindrical cells with various electrode emblies have been used, the flat horizontal cell being oured in recent years owing to its easier manipulation.(5) cell designed by Abramson and described by Moyer,(6) which the separate parts of the Northrop–Kunitz cell(7) e fused together, has been the most satisfactory to date. principles of design and the theory relating to the determination of the electrophoretic mobility of microscopic ticles are well understood for cells of this type. There , however, been a continual search for improved forms of ctrode assemblies and this paper deals with a form likely prove useful in biological investigations.

Early workers used irreversible platinum electrodes, but se were liable to gas evolution and change of pH of the pension medium at high current densities. These were er replaced by reversible $Zn/ZnSO_4$(7) or $Cu/CuSO_4$(8) ctrodes. It is obviously essential to have some means of arating the electrode liquid from the suspension under estigation. This was achieved, in the first instance, with r plugs saturated with potassium chloride. Owing to the inkage of the agar they had to be frequently replaced. this respect plaster of Paris plugs(6) were preferable and, properly prepared and saturated with sodium sulphate, ted six to eight weeks. The authors have had experience h the original Abramson apparatus for the study of microganisms and it was apparent that some improvement in the e of electrode could be made.

The following points were considered.

i) The useful life of the plaster plugs which was partly ermined by the rate at which the copper sulphate solution fused through, was often affected by other factors which were not completely understood. This necessitated renewal of the plug and the consequent interruption of work.

(ii) The proximity of saturated copper sulphate solution to the biological suspension is not desirable. To overcome this difficulty, and at the same time prolong the useful life of the plugs, Hartman(4) interposed a second plug and a chamber of saturated sodium sulphate to separate the electrode liquid from the suspension.

(iii) The closeness of the tap to the surface of the plug can permit the formation of a thin film of grease which possibly results in variations of the electrode characteristics. Further, after long periods of contact with surface active agents or dyes, the plugs require extensive washing before further use.

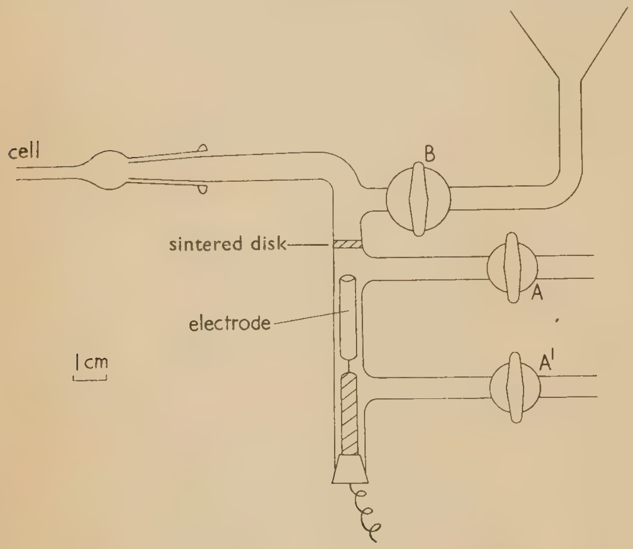
(iv) The use of large taps on the Abramson apparatus causes difficulties in rigid mounting. Failure to achieve this results in movement being transmitted to the cell when the taps are turned.

It was therefore decided to investigate a more convenient and permanent form of apparatus which eliminated the use of plaster plugs.

EXPERIMENTAL

Electrode assembly. A series of experiments were conducted in an apparatus of the Hartman design,(4) using the observation cell in the horizontal plane. Each assembly consisted of a horizontal tube divided into three compartments by sintered glass disks of the finest porosity, instead of the plaster plugs.(4) Taps were inserted in the electrode and central compartments to permit flushing. The electrode was Ag/AgCl in saturated potassium chloride solution. The central compartment was filled with the same M/300 phosphate buffer solution as used for the suspension. Results from this apparatus were very erratic. Rapid and nonsymmetrical diffusion of the concentrated electrolyte in the electrode compartment through the disks gave rapid current variation and the length of the system created unstable hydrodynamic effects.

This apparatus was modified, the central compartment was removed and the electrode compartment bent at right angles to the axis of the cell. A single sintered glass disk separated the electrode compartment from the suspension (see the figure). The taps *A*, *A′* for flushing the electrode compartment were retained and the tap *B* for filling the cell was kept close to the upper surface of the sintered disk. All the taps used were of vacuum standard to prevent movement of the liquids. The electrode compartments were connected by B 10 joints to the observation chamber which consisted of two Hysil optical flats (25 × 40 × 0·5 mm) mounted 0·5 mm apart.



Electrode assembly for improved micro-electrophoresis

The electrodes consisted of strips of silver (8 × 3 × 0·015 cm thick) rolled into small cylinders which were soldered to platinum wire. These were anodized in hydrochloric acid before use. A solution of 3·5 M potassium chloride was used as the electrode liquid.

The source of potential was a 120 V high tension battery. To maintain a constant current during the period of observation a resistance unit of the type described by Abramson(9) was used. The field strength was determined from conductance and current data as described by this worker.

The bacteria were more conveniently observed by using an inclined mirror on the eyepiece of the microscope to project an image on to a screen. A ×40 panchromat was used for the objective in conjunction with a ×10 eyepiece which carried a cross-hatch graticule. A 250 W mercury vapour lamp provided the source of illumination and a cell of water was interposed as a heat filter. The cell was thermostatically controlled at 25° C to avoid fluctuations of the viscosity and resistance of the solution which cannot be completely corrected for by calculation.

Technique. Before a determination each electrode compartment was flushed well and finally filled with 3·5 M potassium chloride solution, care being taken to ensure that no bubbles collected under the sintered disks. The rest of the apparatus was then cleansed by flushing through with glass distilled water, followed by the suspension medium. The bacterial suspension was then admitted and the taps closed. Observations were made at the lower stationary level, i.e. 0·79 of the total depth from the top inside of the cell. Bacteria cultured and suspended as previously described(10) were timed over a determined distance in both directions b reversing the polarity of the electrodes. The current w measured and hence the field strength calculated. A minimu of ten observations obtained in this way was used to calcula the average mobility.

The cell was calibrated using a suspension of human r blood cells, the mobility of which in M/15 phosphate buff solution at pH 7·35 is 1·31 ± 0·02 μ s^{-1} V^{-1} cm^{-1}.(11)

EXPERIMENTAL RESULTS

The symmetry of the observation chamber was first checke using the method suggested by Hartman.(4) Bacteria we timed over the same distance under constant field strength different levels in the cell. The curve in which the reciproc time is plotted against the depth of the cell conforms to parabolic profile, indicating the symmetry of the ce Graphical integration according to the method of Ellis(1 shows the stationary levels to be situated at depths of 0· and 0·79 from the top of the cell, in accord with the theory Smoluchowski.(13)

Over a period of twelve months the average mobility Aerobacter aerogenes grown in synthetic medium h remained constant at a value of 2·37 ± 0·04 μ s^{-1} V^{-1} cm This is in agreement with the findings previously reported.(10 The mobility is independent of the applied field strength.

DISCUSSION

The apparatus has now been in constant use for two yea during which time its performance has been satisfacto The use of smaller taps results in much less torque about th mounting, thus safeguarding the cell from movement. Th chief merits of this inexpensive assembly are its permanenc in that it does not have to be dismantled at regular interval and the reproducibility of the results. Further, it gives mo consistent results than the conventional apparatus at hig field strengths (of the order of 10 V/cm).

In conclusion, the authors have demonstrated the applica bility of the new design of micro-electrophoresis apparat and have shown that the electrophoretic mobilities obtain with it are in very close agreement with those previous reported from this laboratory using the Abramson assembl

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Experimental investigations of the dead time of univibrators

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In a series of measurements carried out on several types of plate-to-grid-coupled univibrators (mono-stable multivibrators) triggered by negative pulses it was found that the dead time strongly depends on the amplitude of the triggering pulse. It has been proved experimentally that this effect leads to time lags if the univibrator is triggered by pulses of a Geiger–Müller counter.

the course of our measurements of the mean life time of nesons(1) an effect was found which seemed to be con-ted with the dead time of the univibrators used for the enching of Geiger–Müller counters. In the following we e an account of the measurements we performed in order clear up this effect.

MEASUREMENT OF DEAD TIME(2)

The univibrator under investigation was triggered by uble pulses. By means of an oscilloscope connected to output, the interval between the double pulses in which univibrator can be triggered a second time (dead time) s determined.

In some measurements the oscilloscope was substituted by pulse counting system in order to study the transients. iggering pulses are counted by means of this system only that case where the interval between the double pulses is s than the dead time. Another counting system of the me type was employed for the counting of the triggering lses; the dead time of this was less than that of the ivibrator.

DEPENDENCE OF DEAD TIME UPON THE TRIGGERING AMPLITUDE(2)

The dead time of several types of univibrators used in our oratory was determined with the above-mentioned methods as a function of the amplitude of the triggering pulses and of the internal resistance of the triggering generator. The univibrators were plate-to-grid-coupled and triggered by negative pulses. It was found in all cases that the dead time increases roughly exponentially with decreasing triggering amplitude. The dead time slightly depends also on the internal resistance R_b of the triggering generator: the greater the internal resistance, the longer the dead time.

By way of illustration Fig. 1 and Fig. 2 show the characteristics of dead time for a "slow" and for a "fast" univibrator where T is the pulse width of the univibrator, and V_n is the normal (corresponding to $t = \infty$) starting voltage.

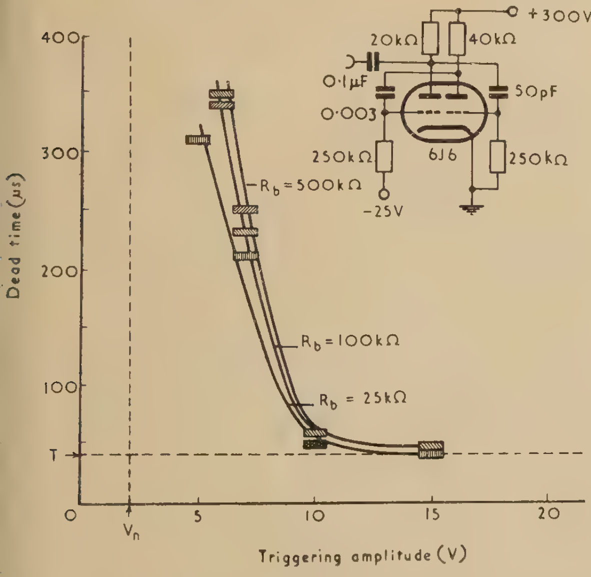

Fig. 1. The dependence of the dead time on the triggering amplitude for a "slow" univibrator

T = pulse width of the univibrator.
V_n = normal starting voltage.
R_b = internal resistance of the triggering generator.

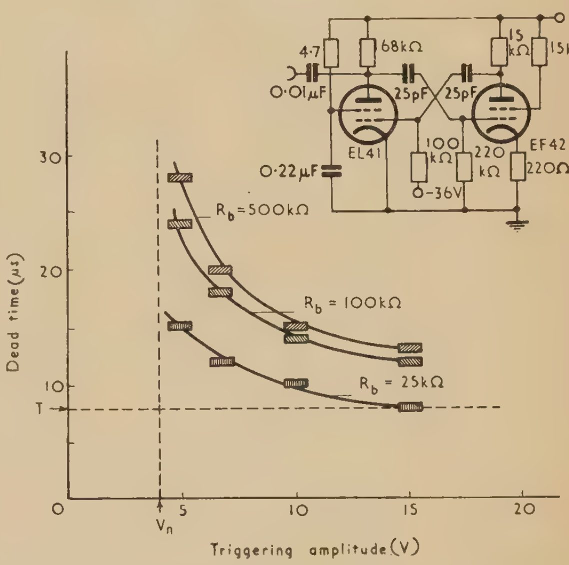

Fig. 2. The dependence of the dead time on the triggering amplitude for a "fast" univibrator

The amplitude dependence can be explained qualitatively as follows. After swinging back the univibrator, the grid voltages and so the sensitivity of the univibrator only gradually reach their original values. Consequently, the smaller the triggering amplitude the longer the time interval between the double pulses needed to flip over the univibrator a second time.

The weak dependence of the dead time on R_b may be explained by the parallel coupling of the internal resistance of the generator with the plate- and grid-resistance of the univibrator.

AMPLITUDE DEPENDENCE AND TIME LAGS(3)

Owing to the finite rise time of the triggering pulse the univibrator responds to the triggering pulse after some delay. The delay depends on the sensitivity of the univibrator. The effects occurring in the interval of decreased sensitivity after the flip-back of the univibrator are registered with a greater delay than those at full sensitivity. The probability of the event taking place in an interval of decreased sensitivity increases with the counting rate of the events.

Thus it can happen that the rate of the delays of a univibrator triggered by Geiger–Müller pulses increases considerably if the counting rate of the Geiger–Müller counter is increased. For instance, by connecting other counters in parallel or by a radioactive substance.

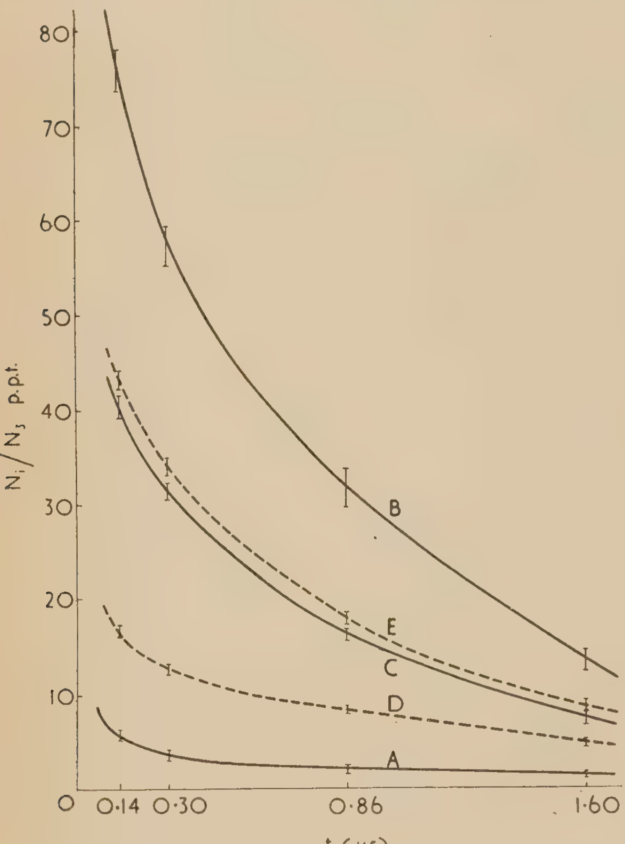

Fig. 3. Delay distribution for a "slow" quenching univibrator

Curve *A*, 10 Geiger–Müller counters at zero cathode voltage connected in parallel with counter *X*; curve *B*, 10 Geiger–Müller counters at normal cathode voltage connected in parallel with counter *X*; curve *C*, 5 Geiger–Müller counters at normal cathode voltage and 5 Geiger-Müller counters at zero cathode voltage connected in parallel with counter *X*; curve *D*, counting rate of counter *X* was increased by a radioactive substance; curve *E*, 10 Geiger–Müller counters at zero cathode voltage connected in parallel with counter *X*; at the same time the counting rate of counter *X* is increased by a radioactive substance.

This effect was proved experimentally by means of a four-channel delayed coincidence system.⁽¹⁾ Figs. 3 and 4 show the integral delay distribution referring to the "slow" and the "fast" univibrator measured above. The values on the ordinate give the total number of delayed events N_i, the delays of which are bigger than the corresponding time shown on the abscissa. The values are given in parts per thousand of the threefold coincidences N_3. The standard statistica errors are also indicated in the graph. The figures prov that the rate of relative delays increased when the counte was connected in parallel with Geiger–Müller counters at normal voltage (see top curve). The increase of the rate o delays is roughly proportional to the increase of the countin rate.

The result is essentially the same as when increasing th counting rate by a radioactive substance (see broken curves especially in the case of simultaneous capacitive loading o the univibrator.

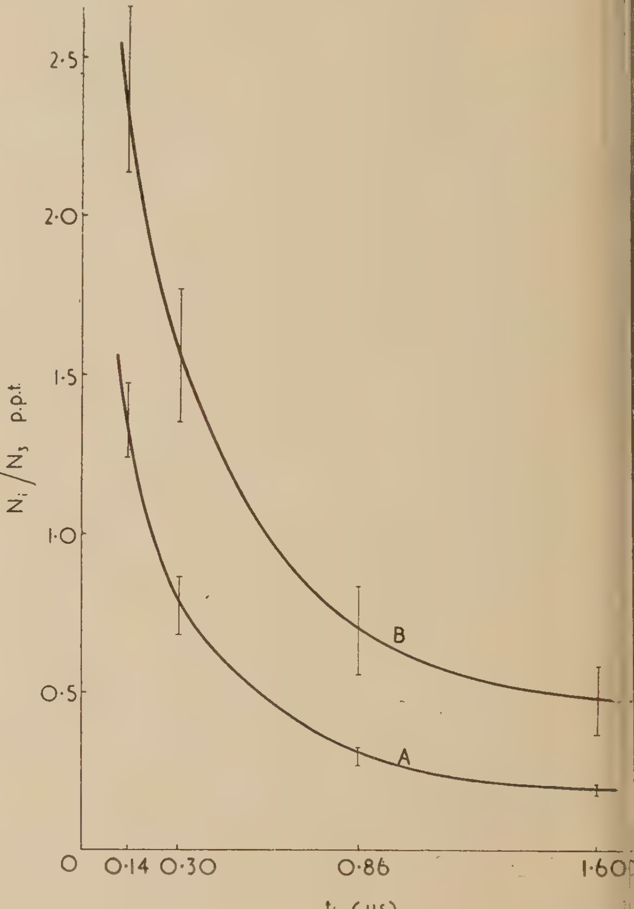

Fig. 4. Delay distribution for a "fast" quenching univibrator

Curves *A* and *B* correspond to those in Fig. 3.

The effects enumerated are due to the dependence of the dead time of the univibrator on the amplitude of the triggering pulse. This view is supported by the results obtained with the univibrator: the increase of delay is less with the "fast" univibrator than with the "slow" one.

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An improved technique for the measurement of contact potential differences

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A development of the vibrating-capacitor method is described. It is used for the measurement of contact potential-differences between a standard electrode and an area of about 1 square millimetre of a metal surface immersed in an insulating liquid. Discrimination against circuit noise is achieved by homodyne rectification. A novel form of drive for the vibrating-capacitor is used. Contact potential differences may be measured to an accuracy of 0·1 mV.

INTRODUCTION

e method to be described is a development of the Kelvin ocedure(1) as modified by Zisman.(2) A very small vibrating ctrode is used so that not only can fine variations of contact .. over the surface of a piece of metal be measured, but the ermination can also be carried out in a liquid medium. proved means for maintaining the vibration and for ecting the extremely weak audio-frequency signals are orporated.

n the Zisman method (Fig. 1) the pieces of metal whose ntact p.d. is to be measured form the plates A, B of a pacitor C_v connected with the grid of an electrometer triode pentode D provided with a leak R of very high resistance. A is connected to earth an electrostatic field is set up tween A and B since they are of different metals and are nnected by R. Vibration of either A or B towards the other ll vary the capacitance of C_v and will cause an alternating tential to appear on the grid of D. If, now, A is suitably ised by means of a potentiometer the disappearance of the nal on D indicates the vanishing of the field in C_v; the tentiometer reading V_p is then numerically equal to the ntact p.d. V_c between A and B. The a.c. signal voltage in e out-of-balance condition is a small fraction of the residual d. $V_p - V_c$ and must be greatly amplified before detection headphones or otherwise is possible.

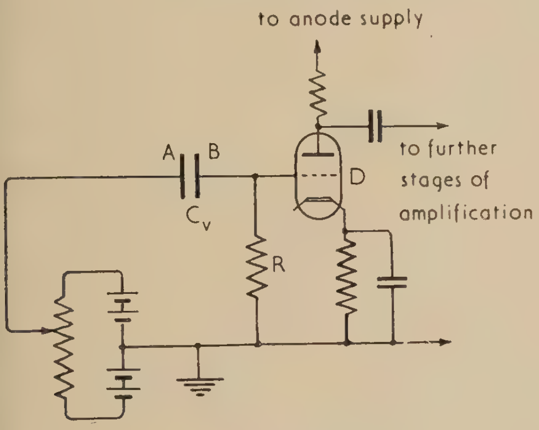

Fig. 1. Principle of Zisman's method

When C_v is of necessity totally enclosed the problem of aintaining A or B in vibration has to be solved in some ay other than the conventional one of applying an alternating agnetic field to an iron armature attached to the vibrating stem. If this were done the electromagnetic e.m.f. would terfere with the measurement. To avoid this the following ethods have been used.

Frost(3) employed a mechanical drive (cam and follower). Zisman(2) attached to a flexible diaphragm in the enclosing vessel a stretched wire which was caused to vibrate by means of an air-blast. Other workers used a moving coil loudspeaker movement inside the enclosure. Excitation frequencies of 60 c/s,(4) 200 c/s(5) or 800 c/s(6) were employed. Mignolet(7) constructed his enclosing vessel in the form of a hollow tuning fork, one prong of which was vibrated (by means of an electromagnet) at twice the frequency of the current in the winding. The fixed electrode was located inside the other prong of the fork.

In all the cases quoted resistance-capacitance coupled amplifiers were used and the indicating instrument was either an oscilloscope or a pair of telephones. In most of these methods a discrimination of 5 or 10 mV is claimed, though it must be remembered that the plate-areas were relatively large (about 20 cm^2 in one case(5)).

It is of interest to note that a single displacement of the movable electrode (as described by Kelvin) has recently been used in conjunction with electronic detection methods. Thus Meyerhof and Miller(8) produced a pulse of potential by bringing the plates rapidly together and suddenly stopping the motion when there was 0·01 in. separation. Harper(9) using the same method employed a final separation of only 0·001 in. When the bias control was out of adjustment the pulse propagated through the amplifier was rendered visible on the screen of an oscilloscope. A sensitivity of 0·01 V for an electrode area of 2 mm^2 was claimed.(8)

THE PROBLEM

The problem before the authors was that of measuring the contact potential of a small area (about 1 mm^2) of the surface of a $\frac{3}{8}$ in. metal ball forming the cathode of a pair of similar electrodes immersed in hexane for the purpose of investigating the impulse breakdown strength of the liquid. The containing vessel was of glass and had to be as small as possible (about 50 mm diameter). This ruled out loudspeaker mechanisms inside the vessel.

Some time was spent investigating a suggestion(10) that the enclosed electrodes whose contact p.d. was to be measured need not be relatively movable; instead, an external vibrating capacitor could be used. This attractive idea was shown, both theoretically and experimentally, to be unworkable. The choice then lay between vibrating and impulsively moving the reference electrode. In view of the need for a wide band of frequencies throughout the equipment in the latter method it did not seem possible for this to compete in signal-to-noise ratio with a method employing a single frequency. Accordingly the vibrating electrode method was chosen. The frequency was decided by the relative claims of electrical sensitivity, which would require a high frequency, and viscous damping and wave propagation in the liquid in which the measurements had to be done. These latter considerations would call for a low frequency.

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Moreover, a limit is set to the product of frequency and amplitude of vibration by the threshold of cavitation in the liquid.(11) For example, in hexane at atmospheric pressure the frequency must theoretically not rise above about 1200 c/s if an amplitude of 20 μ is to be maintained. Accordingly this frequency was adopted, thus ruling out conventional mechanical driving mechanisms.

The chief advantage of the vibrating electrode lies in the possibility (not exploited by the workers cited) of narrowing the band of amplified frequencies to an extreme degree to discriminate against circuit noise. In the present case this was done by employing frequency-selective amplification and synchronous rectification, which reduced the band-width to about 0·1 c/s, enabling a very small vibrating electrode and a small amplitude of vibration to be used. The advantages of these conditions will be seen later.

The problem of maintaining vibration inside a hexane-filled glass vessel which was permanently attached to an all-glass distillation system was solved by supporting the vibrating electrode *A* (Fig. 2) on one end of a stainless steel bar *B* clamped at its centre *C* to the insulating block *D* supporting the other electrode and the rest of the electrode system. The block was rigidly attached to the side of the glass vessel which, though held in clamps, could be forced to vibrate with small amplitude by means of a rod (not shown) connecting it to a moving-coil vibration unit (type V. 47) (by Goodman) energized with a few milliwatts of a.c. power at the resonant frequency of the bar (about 1200 c/s). An amplitude of 10–20 μ, measured at the vibrating electrode, could easily be maintained with liquid present.

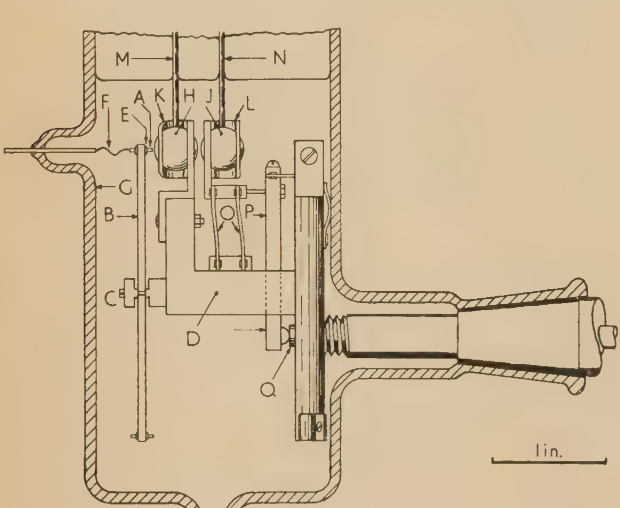


Fig. 2. Apparatus for investigating the electrical breakdown of a liquid, with device for measuring the contact p.d. of the surface of the cathode.

The glass vessel is shown in section. The spherical electrodes *H* and *J* are held by phosphor-bronze springs *K* and *L*, with precautions against scratching when the balls are rotated by means of the contact rods *M* and *N*. The parallel-motion springs *O* enable the gap between *H* and *J* to be varied and measured by means of the 10 : 1 spring-pivoted lever *P* and the micrometer-operated push-rod *Q*. For an explanation of the contact p.d. device see text.

The vibrating electrode was insulated from its support b pyrophyllite bushes *E* and was connected to the input termina of the amplifier by a thin flexible phosphor bronze strip *F* The inside of the glass vessel *G* was coated with metallic gol which served as an electrostatic screen.

DESIGN CONSIDERATIONS

Vibrating capacitor converter

Theoretical expressions for the ratio between the generate alternating potential and the residual contact p.d. (th conversion efficiency) have been given by several workers(10,1 and in a thesis by one of the present authors.(13)

A high conversion efficiency will result if the load resistanc R_L is large compared with the capacitor reactance at th frequency of vibration. Moreover, the harmonic content c the output will then be low even if the capacitance change are non-sinusoidal; a loss of sensitivity when frequency selective amplification is used is thus avoided. In additior the frequency, the static capacitor capacitance C_0 and th fractional change in capacitance should all be high, thoug there will be practical limitations on these quantities of th kinds already mentioned as well as leakage troubles, if R is too high. For example, in the present case C_0 is onl about 0·1 pF, the amplitude of vibration is about 20 μ in mean gap of 100 μ and R_L is 10^9 Ω. A residual p.d. of 1 m theoretically results in a peak signal of about 10 μV only To discern this against the Johnson noise background require a band-width not exceeding 0·6 c/s. This is obtained with a homodyne rectifier(14) which gives other advantages (as wil be seen) as well as that of narrow band-width.

Application of the homodyne principle

The out-of-balance signal *E* (with noise) from the vibratin condenser is applied, together with a reference signal of th same frequency but with a relative phase β, to a homodyn rectifier (Fig. 6). The output of this contains a direct curre i_{dc} proportional to *E* cos β. This current can be exhibited b means of a milliammeter. If β is adjusted to give maximum sensitivity ($\beta = 0$), variation of the capacitor bias through the exact value required to offset the contact p.d. causes i_d to decrease, pass through zero and reverse.

Noise accompanying the original signal produces outpu components which are largely removed by a low-pass filter o band-width $\Delta f'$ following the rectifier. Since the outpu signal-to-noise ratio S_0 is proportional to $|\cos \beta|(\Delta f/\Delta f')^{\frac{1}{2}}$ where Δf is the pre-rectifier band-width, and since for a low pass *RC* network $\Delta f'$ is roughly equal to 1/4*RC*, the us of a sufficiently long time-constant *RC* produces the valu of S_0 required.

However, it should be noted that since the time necessar to obtain information through such a network is of the orde of $(\Delta f')^{-1}$ s, rapid variations of contact p.d. cannot b followed if *RC* is too great. The authors have employed a value of about three seconds, giving a band-width of abou 0·08 c/s and a balancing time of about fifteen seconds which however, is very short compared with the time occupied b changes in contact p.d.

A special advantage of the homodyne technique is that th resulting narrow frequency-band does not require a corre spondingly high stability in the oscillator driving th vibrating condenser. The amplifier band-width Δf may b sufficiently great to accommodate some variation in oscillato frequency. In general the permissible limits of oscillato frequency variation will be governed by the mechanica factor of the vibrating condenser system. In the present e this is about 30, necessitating a frequency stability of out 0·5%.

Since the ratio of the noise in the input to that in the output the rectifier is $(\Delta f/\Delta f')^{\frac{1}{2}}$, care is necessary to avoid over-ding the rectifier with noise.$^{(15)}$ This condition has been isfied by making the amplifier frequency-selective and by signing the early stages of amplification for low noise.

Electronic equipment

A block diagram showing the relationships of the main mponents is given in Fig. 3.

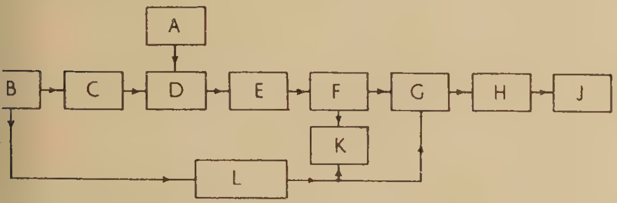


Fig. 3. Block diagram of electrical equipment

A, bias potentiometer; *B*, oscillator; *C*, drive unit; *D*, vibrating capacitor; *E*, head amplifier; *F*, frequency selective amplifier; G, homodyne rectifier; *H*, low-pass network; *J*, null indicator; K, double beam oscilloscope; *L*, phase control and squaring circuit.

Head amplifier. In order to minimize earth capacitance d electrical pick-up a head amplifier, placed close to the ssel containing the vibrating electrode, is employed. It is designed to give freedom from microphonic pick-up, low valve noise and high input impedance. The first valve, type EF37A (by Mullard Ltd.) is accordingly connected as a cathode follower with reduced heater and electrode voltages so that grid resistances up to $10^{10}\ \Omega$ can be used. The head amplifier (Fig. 4) has a gain of about 20 and an input capacitance of about 1 pF. As a precaution against microphonic noise the valves are surrounded with sponge rubber and

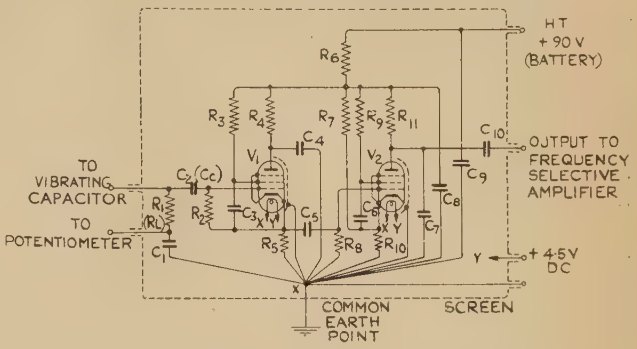


Fig. 4. Circuit of the low-noise head amplifier

$R_1\ (R_L) = 10^9\ \Omega$ (see text)
$R_2 = 10^9\ \Omega$
$R_3 = 75\ \text{k}\Omega$
$R_4 = 67\ \text{k}\Omega$
$R_5 = 6\ \text{k}\Omega$
$R_6 = 15\ \text{k}\Omega$
$R_7 = 33\ \text{k}\Omega$
$R_8 = 1\ \text{M}\Omega$
$R_9 = 470\ \text{k}\Omega$
$R_{10} = 680\ \Omega$
$R_{11} = 220\ \text{k}\Omega$ high stability

$C_1, C_3, C_4, C_6, C_8 = 0{\cdot}5\ \mu\text{F}$
$C_2\ (C_c) = 2$ pF (see text)
$C_5, C_{10} = 0{\cdot}01\ \mu\text{F}$
$C_7 = 500$ pF
$C_9 = 8\ \mu\text{F}$

V_1, V_2 = Mullard EF 37A

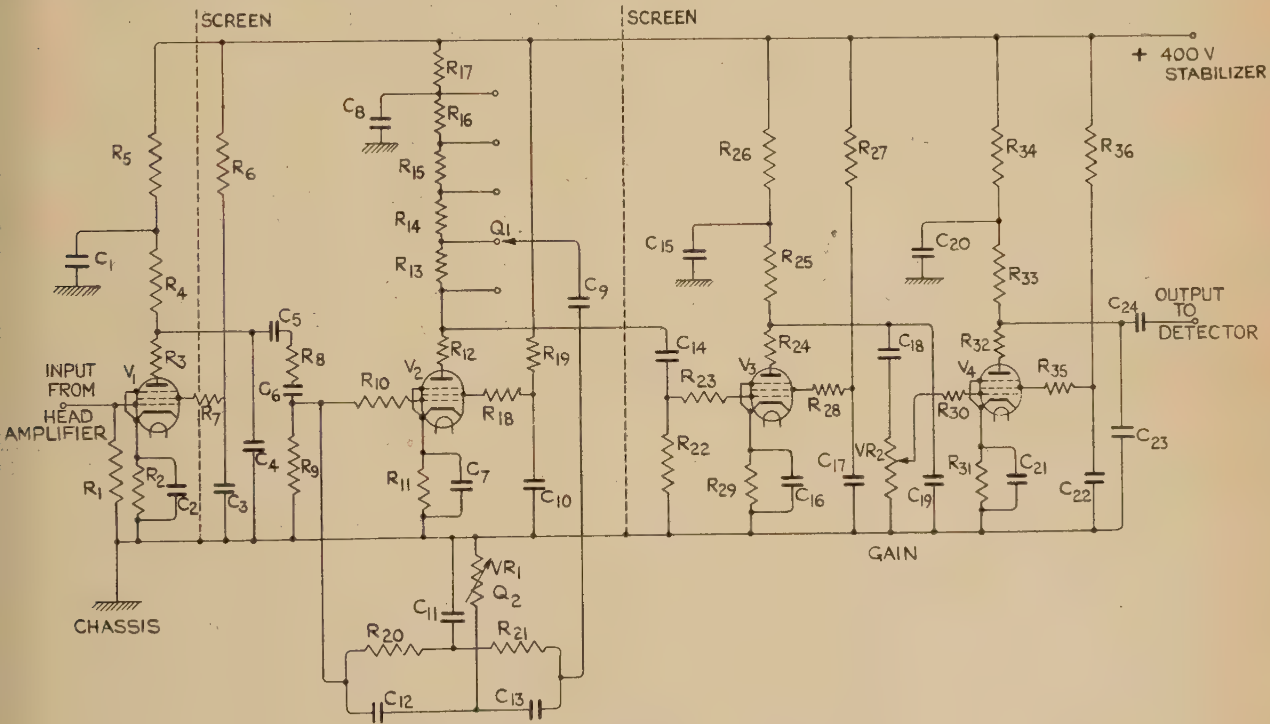


Fig. 5. Circuit of the frequency-selective amplifier

$R_1, R_{22} = 1\ \text{M}\Omega$
$R_2 = 1{\cdot}2\ \text{k}\Omega$
$\left.\begin{array}{l} R_3, R_7, R_{10}, R_{12} = \\ R_{18}, R_{23}, R_{24}, R_{28} = \\ R_{32}, R_{35}, R_{30} = \end{array}\right\} 47\ \Omega$
$R_4 = 100\ \text{k}\Omega$
$R_5, R_{26}, R_{34} = 4{\cdot}7\ \text{k}\Omega$
$R_6, R_{19} = 330\ \text{k}\Omega$
$R_8, R_9 = 1{\cdot}2\ \text{M}\Omega$

$R_{11} = 560\ \Omega$
$R_{13}, R_{14} = 12\ \text{k}\Omega$
$R_{15} = 3{\cdot}3\ \text{k}\Omega$
$R_{16} = 2{\cdot}7\ \text{k}\Omega$
$R_{17} = 5{\cdot}4\ \text{k}\Omega$
$R_{20}, R_{21} = 250\ \text{k}\Omega$ (matched)
$R_{25}, R_{33} = 10\ \text{k}\Omega$
$R_{27}, R_{36} = 47\ \text{k}\Omega$
$R_{29}, R_{31} = 200\ \Omega$

$VR_1\ (Q_2) = 125\ \text{k}\Omega$
VR_2 (gain) $= 1\ \text{M}\Omega$

$C_1, C_8, C_{15}, C_{20} = 16\ \mu\text{F}$
$C_2, C_7, C_{16}, C_{21} = 25\ \mu\text{F}$
$C_3, C_{10}, C_{17}, C_{22} = 0{\cdot}1\ \mu\text{F}$
$C_4, C_{11} = 0{\cdot}001\ \mu\text{F}$
$C_5, C_{14}, C_{18}, C_{24} = 0{\cdot}01\ \mu\text{F}$

$C_6 = 100$ pF
$C_9 = 0{\cdot}5\ \mu\text{F}$
$C_{11} = 2 \times C_{12} = 2 \times C_{13}$
$C_{12}, C_{13} = 500$ pF (matched)
$C_{19}, C_{23} = 0{\cdot}005\ \mu\text{F}$

V_1, V_2 = Mullard EF 37A
V_3, V_4 = Mullard EF 50

compliantly mounted. The whole unit is shielded and further surrounded with sponge rubber. Important tests for the presence of microphonic signals are described later.

Frequency-selective amplifier. This is a 4-stage resistance-capacitance coupled unit having a maximum gain of about 5.10^6 at 1260 c/s with a band-width of approximately 500 c/s obtained by the use of frequency-selective negative feedback around one stage and with capacitively-shunted anode loads in the remaining stages to reduce the gain at high frequencies (Fig. 5). The Q-factor may be varied by controls Q_1 and Q_2 to permit contact potential measurements in the range 1000 to 1400 c/s for testing purposes as later described.

Homodyne rectifier. The circuit is given in Fig. 6. For the analysis of a similar type of circuit see the paper by Farren.(15) The reference voltage is derived from the output of the a.f. oscillator driving the vibrating condenser. To improve the linearity of the rectifier the reference voltage waveform is rendered approximately rectangular in a conventional limiting circuit. This feature is not, however, essential. As the output of the rectifier is a maximum when the signal and the reference voltage are in phase (or π radians out of phase) a phase-shift circuit precedes the limiter to permit variation of β from 0 to 2 π without changing the output level of the reference voltage.

The signal and reference voltage waveforms at the input to the detector are displayed directly on the screen of a double-beam oscilloscope, to facilitate their phase adjustment before balance is obtained. Means are also provided for pre-setting the reference voltage level so that the detector will operate under conditions of maximum sensitivity for a given signal input.

The low-pass network following the detector has a range time constants from 3 s to 0·05 s which result in detector ban widths of approximately 0·08 c/s to 5 c/s respectively. T output from the filter is fed to a pair of balanced cathod followers across whose cathodes a centre-zero meter (±1 m serves as the null indicator.

Earthing and decoupling precautions. In accordan with normal practice for the amplification of small ($\simeq 10^{-}$ signal voltages, a system of "one point" earthing to a poi near the high impedance input terminal of the pre-amplifie is essential. This involves, particularly, the earth leads to th potentiometer, the pre-amplifier, the electrostatic and th magnetic shields surrounding the vibrating capacitor an containing vessel.

In the interests of stability, the pre-amplifier is operate from batteries, while the tuned signal amplifier is fed from a stabilized h.t. supply. To eliminate remaining decouplin problems, it has also been found necessary to provide separat h.t. supplies for the limiter stage and the homodyne.

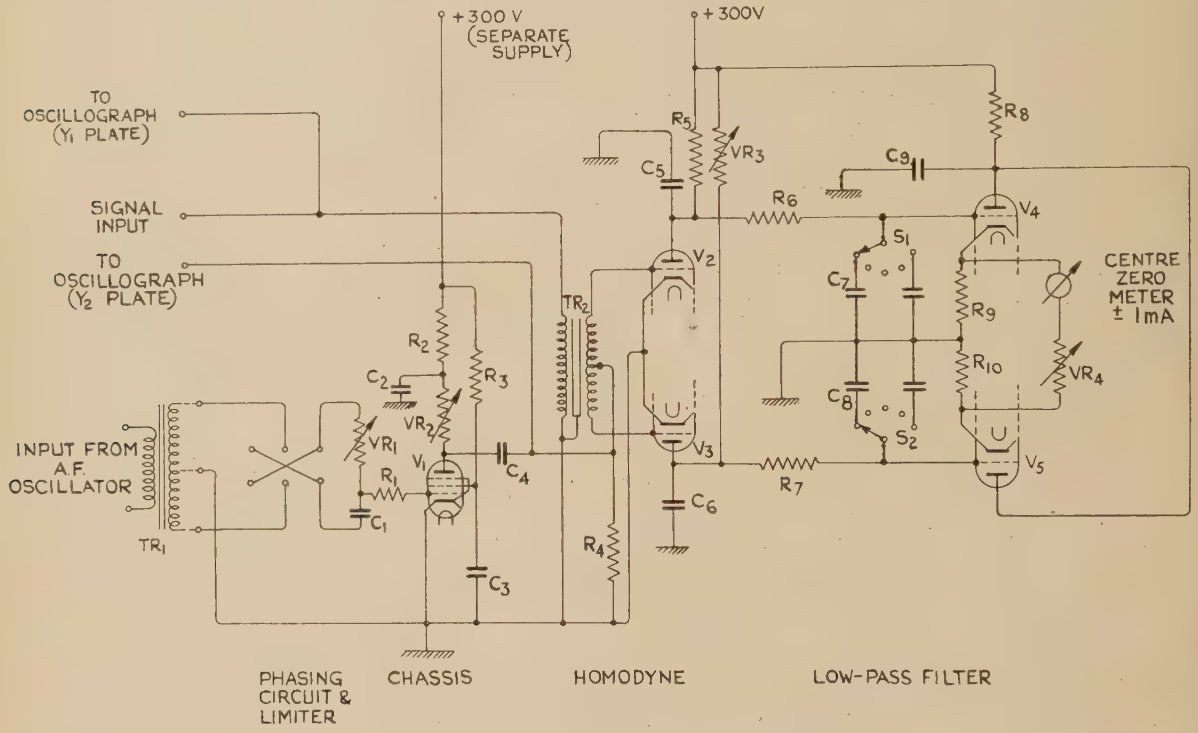


Fig. 6. Circuit of the homodyne rectifier

$R_1, R_4, R_6, R_7 = 1$ MΩ
$R_2 = 47$ kΩ
$R_3 = 330$ kΩ
$R_5 = 50$ kΩ
$R_8 = 3{\cdot}3$ kΩ
$R_9, R_{10} = 12$ kΩ

VR_1 (phase adjustment) = 100 kΩ
VR_2 (reference voltage level) = 5 kΩ w/w
VR_3 (meter set zero) = 50 kΩ w/w
VR_4 (meter sensitivity) = 30 kΩ w/w

TR_1 = oscillator output transformer (ratio governs value of VR_1 and C_1)
TR_2 = push-pull driver transformer (Ferranti)

$C_1 = 0{\cdot}002$ μF
$C_2 = 16$ μF
$C_3, C_4 = 0{\cdot}1$ μF
$C_5, C_6 = 0{\cdot}25$ μF
$C_7, C_8 = 0{\cdot}05$ to 3 μF
$C_9 = 1$ μF

S_1, S_2 = S.P. 5-way ganged
V_1, V_2 = Mullard EF 37A
V_3, V_4 = Mullard EF 50

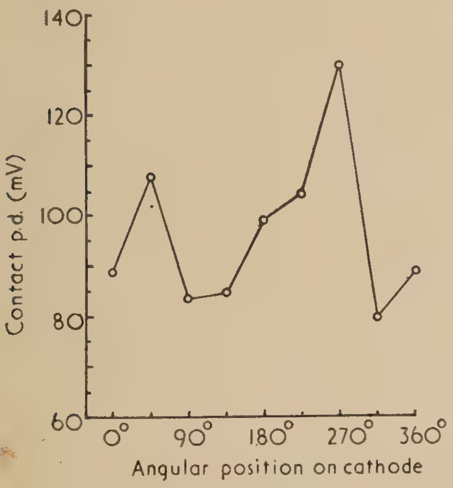
EXPERIMENTAL PRECAUTIONS

Because of the minute signal generated by the vibratin capacitor, it is important to confirm whether or not i originates from a true contact potential. Two useful test involve observing the effect of (i) varying the mean capacito plate spacing, and (ii) reversing the electrical connexions t the vibrating capacitor. In a satisfactory system, test (should show no change of balance potential (except perhap at very narrow gaps when surface "patch" fields may interfere) while test (ii) should result in a balance potential of the sam gnitude but opposite sign. If the capacitor gap is very rrow, non-parallelism of the plates may cause variation of apparent contact p.d. with gap,[(16)] although the present hors observed no change when the test electrode was rated against a spherical and then a plane metal surface. Since this apparatus is capable of detecting a potential of y 10^{-4} V across $10^9\,\Omega$ (R_L), it is clearly important that re should be very low leakage in C_v and C_c (Fig. 1).

Leakage in C_v may be checked by the "reversed connexion" t, or, if this is impracticable, a change in the value of R_L a factor of 10 to 100 should not affect the balance position. e authors found that the small bushes *E* of fired pyro-yllite supporting the reference electrode in the vibrating (Fig. 2) provided adequate insulation.

Leakage in C_c may be checked quite simply by varying the supply voltage to the pre-amplifier. This changes the grid ential of V_1 (Fig. 4) and results in a linear shift of the ance point with h.t. voltage, if leakage is significant. In ler to obtain a capacitor with satisfactory insulation the hors used a home-made 2 pF polystyrene dielectric acitor for C_c; this had a leakage resistance of $10^{15}\,\Omega$. The t-mentioned test will also show up microphonic signals due any vibration of the grid of V_1 (Fig. 4).

Palevsky, Swank and Grenchik[(17)] have suggested that ration of the insulated electrode may cause the generation a spurious e.m.f. In the case of the authors' apparatus s construction was essential to reduce the effects of stray acitance across C_v, but no spurious signals were obtained.



ig. 7. Typical set of observations: the variation of contact p.d. around the circumference of the cathode ball when immersed in *n*-hexane

Apart from that due to microphonic signals, a "noisy" ance point may arise from signals generated by stray brating" capacitances, e.g. between the test electrode and surrounding electrostatic screens. By isolating each een in turn and applying bias voltages, the source of signal y be traced, and the screen position (or metal) suitably nged. In principle, the work function of the screen metal uld be similar to that of the vibrating electrode for then "vibrating" stray capacitances produce no signal. The "reversed connexions" test is again a good check on the influence of such strays on the position of the balance point.

Rotation of the rectifier phase-shift control (Fig. 6) also provides a very sensitive indication of the absence of signal at the apparent balance point. When the system is operating correctly the balance point will also be independent of the frequency and amplitude of vibration of the condenser.

PERFORMANCE

Fig. 7 shows a typical set of observations made with the apparatus. Abscissae represent positions around the diameter of the cathode ball and ordinates show the mean contact p.d. over an area of about 1 mm^2 at each point. The readings were reproducible within 0·1 mV.

ACKNOWLEDGEMENTS

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Improving the linearity of barrier-layer photocells

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A modification of the Campbell–Freeth circuit is described, whereby the effective series resistance of a barrier-layer photocell, in so far as it is constant, may be eliminated. The results suggest that the series resistance includes part of the barrier-layer.

The barrier-layer photocell consists of a steel base-plate (1 in. diameter for a small cell), on which is deposited a thin layer of pure selenium in the annealed crystalline state; this forms the positive electrode. The negative electrode, which is sputtered on the selenium, consists of a translucent film either of gold with an oxide layer between it and the selenium, or of cadmium oxide. Electrical connexion to it is made by means of a ring of Wood's metal sprayed on the surface near the periphery.(1)

When light is incident on the cell, electrons are ejected from the selenium at a rate proportional to the illumination, and pass to the oxide, where a space charge is set up. This brings about a potential difference across the interface (or barrier-layer) between the electrodes, so that a reverse current flows. In equilibrium, the net current crossing the barrier-layer is zero. If an external circuit is connected between the electrodes, part of the reverse current flows through it, the amount depending on the resistance in series with this circuit relative to that of the barrier-layer.(2)

Experimental results are in agreement with these ideas of the cell mechanism, and have led to the adoption of an equivalent circuit(3–5) to explain, in electrical terms, the behaviour of the cell (see Fig. 1). In this circuit, g represents a perfect photoelectric generator which produces a current i proportional to the illumination; r is the equivalent of the non-ohmic barrier-layer resistance through which the reverse current within the cell passes; C is the effective capacitance of the cell, and R_s its series resistance. R is the resistance in the external circuit. Usually, R_s has been supposed to consist of the resistances of the cell electrodes,(6, 7) although Sandström has remarked that a portion of the barrier-layer resistance may be included.(8) Some idea of the magnitudes of the circuit elements in Fig. 1 may be got from the constructional details of the cells, and from d.c.(9) and a.c.(10) measurements. Thus, it is known that the resistance of the selenium layer is of the order of 100 Ω, and that of the transparent film about the same, or possibly less in modern cells.(11, 12) The value of C is of the order of $0 \cdot 1\ \mu$F, while that of r may be between several hundred and many thousands of ohms, depending on both the illumination and the voltage across the barrier-layer.

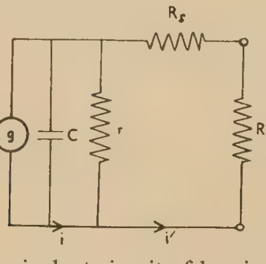

Fig. 1. Equivalent circuit of barrier-layer cell

Some undesirable properties of the barrier-layer photocell, such as non-linearity, temperature sensitivity, and fatigue, have limited its use for precise photometric measurement.(13) These effects are partly attributed to the dependence of th external photocurrent i' on variations in r. Such variation will have less effect when R is small than when it is large In particular, if the potential across r could be reduced t zero when i' was measured, the result would be independen of the value of r. Thus, the non-linearity usually takes th form of the output current increasing less rapidly than th illumination, and the effect is greater when R is large tha when it is small.(14–17) Accordingly, it was at one tim usual, when accurate work was attempted, to measure th cell current with a low resistance galvanometer. The dis advantage of this was that such galvanometers are relativel insensitive. However, this difficulty was overcome in th circuit devised by Campbell and Freeth.(18)

THE CAMPBELL–FREETH CIRCUIT

The circuit is shown in Fig. 2. In use, the potentiomete P is adjusted, for a given illumination, so that G shows deflexion. If R_s were absent (as the authors of this circu originally supposed), there would be no potential differen across r, and no reverse current would flow through the cel The primary photoelectric current i would flow through th meter M, and would be recorded. Owing to the presence R_s, this ideal result is not achieved. However, since there i no difference of potential across G, the resistance in th external circuit is reduced to R_s. This arrangement, a Campbell and Freeth showed, not only makes the ce response more linear, but also makes the cell less sensitiv to temperature. This has remained the standard circuit fo accurate work.

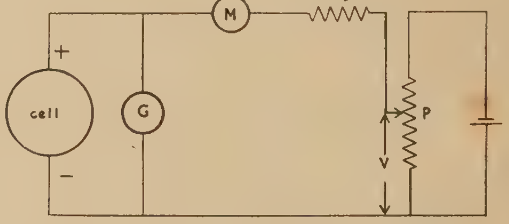

Fig. 2. The Campbell–Freeth circuit

The purpose of this paper is to draw attention to a simpl modification of the Campbell–Freeth circuit, whereby th series resistance R_s of the cell, in so far as it is constant, ma be eliminated.

THE MODIFIED CAMPBELL–FREETH CIRCUIT

The modified circuit is shown in Fig. 3. The potentiomete P is adjusted so that G shows no deflexion. Then, i $R_g/R_s = R_1/R_2$, the potential across r will be zero. Th whole photoelectric current i will thus flow in the externa circuit, where it can be measured. The most convenien arrangement is to make R_1 and R_g equal. The potentia oss r will then be zero when $R_2 = R_s$. The sensitivity is atest when R_1/R_2 is large, and the photocurrent may be her measured by the meter M, or calculated from the pression $R_1 V/R_g(R_1 + R_2)$.

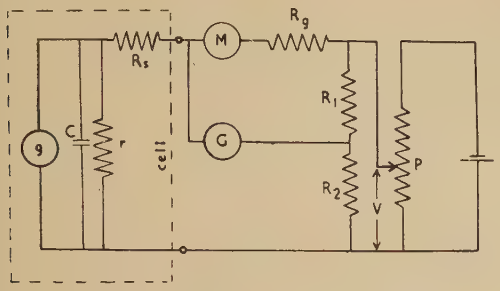

Fig. 3. The modified Campbell–Freeth circuit

The operation of the circuit can be understood from the aracteristic curves of the cell, that is, the graphs of external rrent v. terminal voltage for different illuminations. These shown in Fig. 4 for one cell (No. 2) used in the present rk. The number written on each curve represents relative umination. The values of current which would flow ough a load of $R\,\Omega$ at the different illuminations can be tained by noting the points of intersection of the cell aracteristics with a straight line through the origin making angle $\tan^{-1}(1/R)$ with the abscissa. When the Campbell–eeth circuit is used, the voltage between the cell terminals zero at balance, and the load line coincides with the ordinate ile. The points of intersection of the characteristics with abscissa give the open-circuit voltages of the cell at the ferent illuminations. There is a steady improvement in earity as $\tan^{-1}(1/R)$ increases from 0–90°, which is conued as the load line moves into the negative quadrant, rresponding to the circuit of Fig. 3. The possibility of proving the linearity with the load line in the negative adrant lies in the fact that the response curves for negative ltages are almost straight lines over their useful length, d these lines make angles with the abscissa which increase th increasing illumination.

In connexion with Fig. 4, it is of interest to describe briefly method devised by Blet(19) for obtaining an increased tput voltage from a barrier-layer cell, together with proved linearity. The method consists of connecting a istance and a negative voltage in series with the cell. The rk current which passes with this voltage applied to the l is subtracted (by special circuitry) from the total current ich flows when the cell is illuminated. The resultant hotocurrent" changes more linearly with the illumination as the negative voltage is increased. The load lines corresponding to a resistance of 2000 Ω in series with voltages of 0 and −500 mV are denoted by (*a*) and (*b*) respectively in Fig. 4. The dark current of cell No. 2 is 1·5 μA at −500 mV.

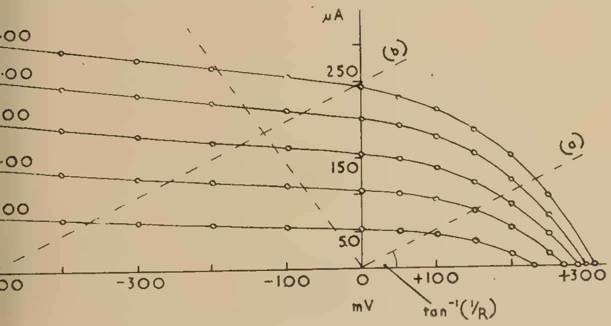

Fig. 4. Characteristic curves of barrier-layer cell

The effect of the circuit shown in Fig. 3 on the linearity of EEL cells (by Evans Electroselenium Ltd.) has been investigated, using the method of Elster and Geitel.(20)

EXPERIMENTAL APPARATUS AND PROCEDURE

Some 6 V car lamps were mounted in a circle 20 cm diameter in the bottom of a box of depth 10 cm and sides 20 × 30 cm. A circular hole, about 1 cm greater in diameter than that of the cell mounting, was cut in the centre of the lid, and covered on the inside surface of the latter with a disk of opal Perspex. The cell was mounted in a temperature-controlled enclosure with its sensitive surface 4 mm above the Perspex. Several coats of matt white paint were applied to the inside of the box.

The illumination was varied by turning on different combinations of lamps. The wiring was arranged so that the potential difference across any lamp was independent of the current drawn by other lamps, and could be adjusted to within 0·0001 V of its nominal value by comparison with a standard cell. The photocurrent was calculated from the resistances and the measured value of the potentiometer voltage V, which was obtained by comparison with a standard cell. The resistances R_1 and R_g (Fig. 3) were made equal, their value depending on the level of illumination. The minimum value was 482·2 Ω, and the maximum 7473·5 Ω. When the lamps had been aged for about 50 h, it was found possible to repeat measurements with individual lamps to 1 part in 1000 over the whole range of illuminations which were used.

The main experiment consisted of determining the effect of the resistance R_2 (Fig. 3) on the linearity of response of the cell. The deviation from linearity at a given illumination was defined by

$$\Delta = \left(\frac{J}{\Sigma I} - 1\right) \times 100\%$$

where J is the cell current obtained with a number of lamps together and ΣI is the sum of the (approximately equal) contributions of the individual lamps, obtained in a separate experiment. The procedure in the main experiment was to switch on the desired combination of lamps, and then to wait until the rate of change of cell current (caused by cell fatigue) was less than 1 part in 10 000 per minute. The cell current was then measured for different values of R_2 in quick succession. The observed variation of Δ with R_2 at a given illumination was thus almost unaffected by cell fatigue. However, the values of Δ at a given illumination and for different values of R_2, were all liable to the same variation of up to 1%, depending on the immediate past history of the cell.

RESULTS

A typical set of results is shown in Fig. 5. These were obtained for the greatest illuminations used, the maximum current being 421 μA ($R_2 = 1000\,\Omega$). It is seen that a value of R_2 equal to 600 Ω results in a considerable improvement in linearity over a useful range of illumination (5 : 1). When the mean level of illumination was less, similar results were obtained, but the value of R_2 which gave best linearity was found to be larger. The optimum values of R_2 were determined for four different levels of illumination, each varying in itself by a factor of three. These values were plotted against the photocurrent recorded at the mean of each level of illumination, for three cells (Fig. 6). Each had a sensitive surface 20 mm in diameter.

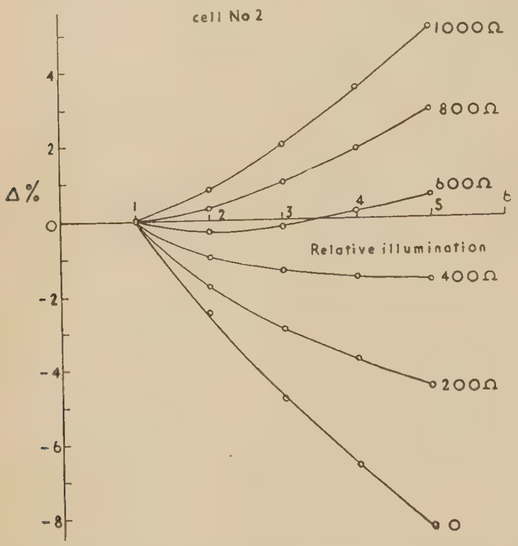

Fig. 5. Curve illustrating percentage deviation from linearity with increasing illumination. The figures given by the curves are the different values of R_2

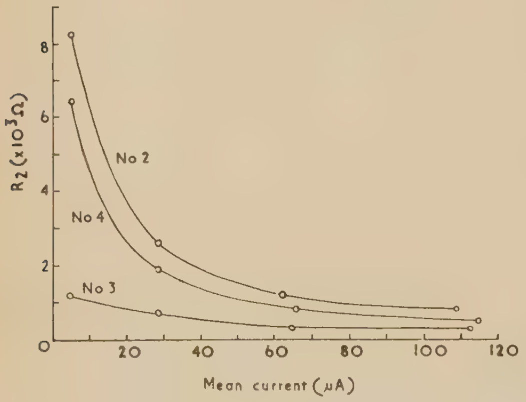

Fig. 6. Optimum value of R_2 against cell current

DISCUSSION

The electrode resistances, which are included in R_s (Fig. 1), consist partly of selenium, and would be expected to diminish as the illumination increased. Therefore it is not to be expected that strict linearity should be observed at all illuminations with a single value of R_2. However, the large values of R_2 which are required for best linearity at low illuminations cannot be explained by variation of the resistance of the selenium. Therefore the series resistance R_s is not that of the electrodes when separate from each other. Also, the curves of Fig. 6 are correlated with those showing the relation between photocurrent and open circuit voltage (Fig. 7). In each case, the curve for cell No. 3 is far removed from the curves for the other two cells. While this might be explained by a leakage resistance of a few thousand ohms between the terminals of cell No. 3, measurement shows that this is not so. This suggests that the serie resistance is related to the open circuit voltage; that is, to th thickness and constitution of the barrier-layer.

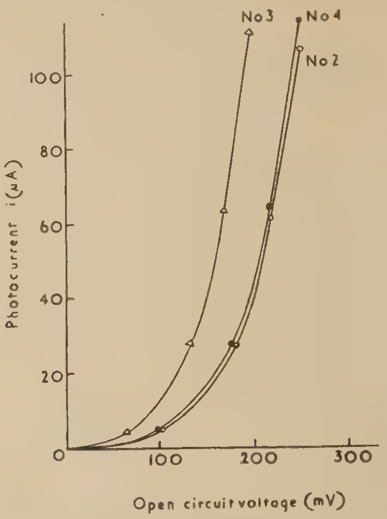

Fig. 7. Photocurrent against open circuit voltage

ACKNOWLEDGEMENT

I am indebted to Mr. J. S. Preston, of the National Physica Laboratory, Teddington, for kindly discussing these result with me, and for drawing my attention to the work of Dr G. Blet.

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A soft valve scaler for intermittent fast counting

By G. W. Hutchinson, M.A., Ph.D., Physics Department, University of Birmingham

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A simple scaling circuit is described in which gas-filled scaling valves are used for counting bursts of radiation without severe counting losses, even when the mean interval between counts within the bursts is much less than the resolving time of the soft valves. To do this, information is stored during the bursts as charge on a condenser and is subsequently read off as a series of evenly spaced pulses by discharging the condenser with a standard repetitive waveform.

ıen counting equipment is used with high energy celerators which produce radiation in short bursts, the an counting rate is often quite slow and yet the resolving ıe of the electronics has to be short because pulses are sely spaced within the bursts. The scaler described in this ɔer was designed to allow gas-filled scaling valves katrons) to be used for such counting, in spite of their ıtively low maximum mean counting rate.

The incoming pulses are each made to deliver a standard ırge to a capacitor. The capacitor is discharged by removing the same charge from it at regular intervals of 1 ms until reaches its quiescent potential. Pulses are produced by :h step of the discharging process and fed to a normal katron scaling circuit and mechanical register. The olving time is determined by the initial pulse-shaping cuit and is made to be 1 μs. The number of pulses which y be counted in any one burst is determined by the missible voltage swing of the capacitor and is about fifteen.

The scaler was designed for use with the Glasgow electron ıchrotron which gives five bursts of radiation per second, length of the bursts being of the order of 10^{-4} to 10^{-3} s. was expected that for many experiments a counting rate of y pulses per second would be adequate. The mechanical gisters used would count reliably at a rate of five pulses second. They were therefore preceded by a single katron scale of ten. The short-term storage system thus d to be able to receive a maximum mean count of ten lses per burst, and a resolving time of 1 μs for the input cuit provided an acceptably low counting loss. This ecification allowed the circuit design to be simple, so that scalers could be made up on sub-chassis and used in ocks of five with a common power supply and discharging veform generator.

The use of a short-term memory in the form of a storage ɔacitor has been described by Bell,* who used the device increasing the speed of a conventional hard valve scaler. his circuit the capacitor was discharged by a trigger circuit ıich was only active while the capacitor was charged. The esent system was developed independently and for much wer counting rates, and it was more convenient to discharge capacitors by means of a free-running generator of 1 kc/s uare waves.

The calculation of counting losses in circuits using short-m storage has been described by Bell.* In the present se the losses may occur partly at the input, where they ıy be calculated in the usual way, and partly at the input the mechanical register. If more than ten pulses are unted in one burst the dekatron may be driven twice to zero position, and it will then deliver two impulses to register separated in time by only 10 ms, so that the cond will be lost. Because of the smoothing effect which preceding scale of ten has on the counting rate, the onset of counting losses at this point is very sharp. At a mean rate of nine pulses per burst they are negligible compared to the random losses at the input. At ten pulses per burst they are about 2%, and at higher rates they rise quickly. Losses due to the finite storage capacity of the short-term memory are negligible, except at very high counting rates at which losses at the input and output stages are already intolerably high.

CIRCUIT DESIGN

The circuit of the scaler unit is shown in the figure. The power supplies common to five units provide stabilized bus-bars at +300 V and −200 V together with an unstabilized supply at about +400 V.

Positive input pulses of amplitude greater than 10 V trigger the first double triode which acts as discriminator and pulse shaper. The resulting pulse, produced at the right-hand anode, is of well defined height and hence causes a standard charge to be placed on the 100 pF Miller capacitor of the following pentode, *via* the 47 pF coupling capacitor and one-half of the double diode. The pentode anode potential is thus caused to fall by a standard amount of about 12 V. Following pulses within the same burst produce additional and equal voltage changes unless the Miller capacitor is discharged before their arrival.

Charge is removed from the Miller capacitor by the negative-going edges of the 1 kc/s square wave applied through the trimmer capacitor and the other half of the double diode. This waveform is generated from one anode of a pair of cathode-connected type 6CH6 valves which are not shown in the figure and are common to five scaler units. Its frequency is not critical and is determined by the capacitor-resistor feedback coupling of the pair. Its amplitude is stabilized since it is derived by switching the current from the common cathode load of the valves, and is arranged to be about 100 V.

Positive-going voltage steps appear on the anode each time charge is removed, and, by adjusting the trimmer, these are made equal in amplitude to the negative steps derived from incoming pulses. The quiescent state of the pentode is adjusted by the 20 kΩ potentiometer so that it is nearly cut off, and only very small positive signals appear at its anode from the square waveform unless the capacitor is in a charged state.

The pentode anode waveform is differentiated and then applied to the following double triode trigger circuit which produces at its anodes the waveforms needed to drive the dekatron. Since the left-hand half of this double triode is normally cut off, it is only the positive-going signals occurring at intervals of not less than 1 ms which produce a triggering action.

The mechanical register is driven from the right-hand anode of the remaining double triode, which is normally cut off, but produces a large current pulse when the left-hand half of

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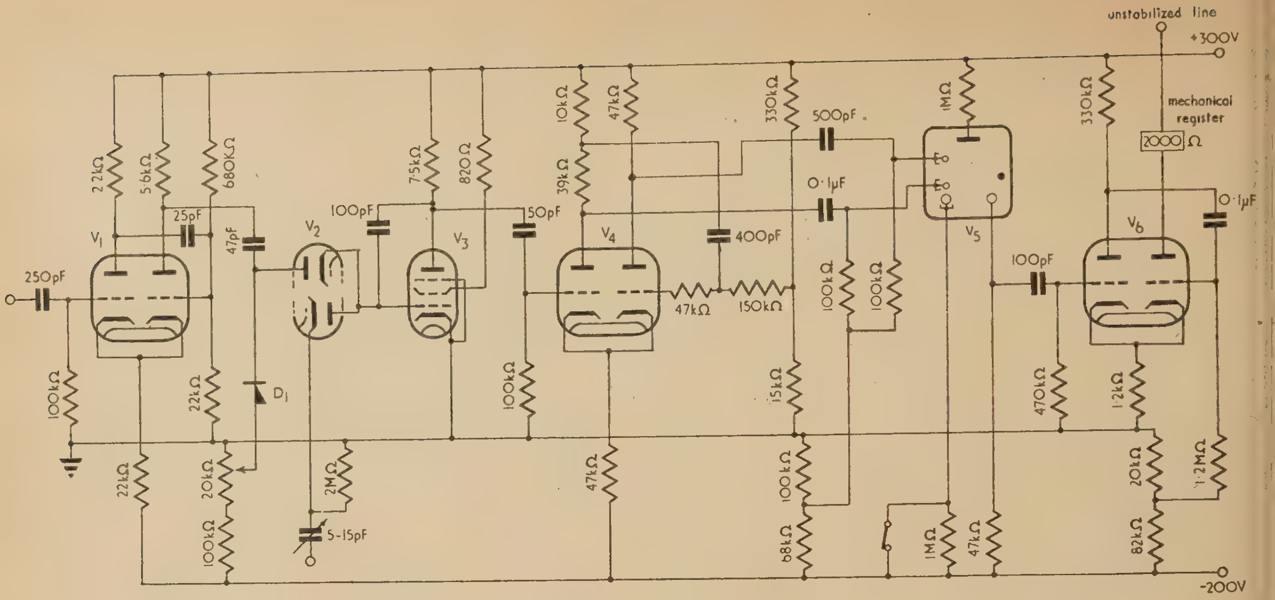
* Bell, R. E. *Canad. J. Phys.*, **34**, p. 563 (1956).



Circuit diagram of scaling unit

V_1, V_4, V_6 = ECC 91 V_2 = EB 91 V_3 = EF 91 V_5 = GC 10 B

the valve is cut off by a negative pulse from the dekatron. The impedance of the register coil is 2000 Ω.

PERFORMANCE

The scalers have been tested both with random pulses and with bursts of pulses derived from a 1 Mc/s oscillator, gated to give standard numbers of pulses during the burst.

The capacitor memory system can be made to store and count up to twenty pulses per burst by careful adjustment, and appears reliable over long periods for the storage of ten to fifteen pulses. Under these circumstances a 5% drift in the relative sizes of the charging and discharging pulses ca be tolerated.

Since the time of arrival of a burst is random with respe to the phase of the discharging waveform, there is a sma standard counting loss from coincidences between th charging and discharging pulses applied to the stora capacitor. When this happens the pulse may not be recorde However, since the falling edge of the square wave lasts fa less than 1 μs, the chance of such a coincidence is of the ord of one part in 1000, and the resulting uniform counting lo is not serious in most applications.

An apparatus for investigating the low-pressure oxidation kinetics of hot metals

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[*Paper received* 4 *October*, 1956]

An apparatus is described for measuring, by a continuous flow technique, the sorption of gas by a hot metal filament. The method is applicable to cases such as the oxidation of titanium in which sorption is so rapid that the "closed volume" technique cannot be used. It has the advantage that the accumulation of impurities in the reaction vessel is avoided. The data of a typical titanium oxidation experiment are given, together with a discussion of accuracy and sensitivity. The apparatus, which includes a simple manostat, is of general suitability for continuously introducing a metered gas flow of the order of 10^2 μl/min into a low pressure system. The same apparatus may be used with closed volume technique for metals such as gold, which react very slowly with oxygen.

The authors recently wished to study the oxidation of hot titanium at pressures usual in technological vacuum practice (of the order of 1 μ of mercury); this led, in addition, to the study of the oxidation of hot gold. This paper describes the apparatus, which is believed to have some novel features. In particular, it permits the attainment of isobaric conditions with sorption rates of the order of 10^2 μl/min.

The oxidation rate of titanium is much greater than that of gold under comparable conditions. It was, however, possible, by a slight change of technique, to study both in the same apparatus. The results for titanium and gold will be reported elsewhere; it suffices to say here that the prob ability of the reaction of oxygen with the hot metal is of th order of unity for titanium and 10^{-5} for gold, at a temperatur of 1000° C and a pressure of 1 μ of mercury.

REQUIREMENTS OF THE DESIGN

It was considered desirable to try to satisfy the followin requirements.

(i) Observations of oxidation rate to be continuous durin the course of the reaction.

(ii) Oxygen pressure to be as nearly constant as possible.
(iii) Accumulation of gaseous impurities in the reaction vessel to be avoided.
(iv) The upper limit of metal temperature to be fixed only by its melting or evaporation—not by the materials of construction of the apparatus.
(v) The observation of physical properties (e.g. electrical resistance and optical appearance) to be possible during the course of oxidation.
(vi) Independent variation of temperature of gas and metal to be possible.

One of the most elegant devices for studying high tempera- re oxidation is the micro-balance of Gulbransen(1,2) which tisfies requirements (i) (ii), is limited in temperature(3) to 00° C, but does not fulfil requirements (iii), (v) and (vi). Wagener(4) has described a method of investigating the te of gas sorption in "getters," by observing the difference pressure at two ends of a capillary tube down which the s flows. This is very convenient at pressures so low that e conductance of the capillary is essentially limited by wall llisions (Knudsen flow) and is therefore pressure indepen- nt. At higher pressure, however, the conductance is not nstant and the method becomes less attractive. In any se it is not applicable to small reaction rates unless the nductance of the capillary is made small which is unfavour- le to requirement (iii).

The method about to be described satisfies all the require- ents listed except (ii), which is only partially fulfilled, as ll be seen below.

PRINCIPLE OF METHOD

For the present purpose it is convenient to express the netics of oxygen/metal interaction by the equation

$$\epsilon = b\eta pA \qquad (1)$$

which ϵ is the reaction rate of the impinging oxygen at essure p, η is the probability that a molecular impingement ill result in oxidation, and is a function of metal tempera- re, state of metal surface and orientation and velocity of npinging molecule, b is the constant of proportionality tween impingement rate and pressure, which depends on e temperature and molecular weight of the oxygen, and A the area of the metal.

The apparatus is shown schematically in Fig. 1. It is used two ways, depending on whether the oxidation rate is arge" or "small." By "large" is meant a rate such that, uring the necessary minimum observation time imposed by e lag of the pressure gauges, there would occur a significant duction of pressure in the reaction vessel, if it were isolated om the source of the gas.

The apparatus was primarily designed for "large" rates, in hich case a "continuous flow" technique is used. The essure P in the gas-holder is adjusted and maintained by a anostat to give a measured flow γ through the fixed throttle, about twice the expected oxidation rate ϵ. A filament of e metal to be oxidized is heated electrically to a pre- etermined temperature, and the pressures p_A and p_B given y Pirani gauge A and Pirani gauge B are noted. Under ese conditions ϵ is given by

$$\epsilon = \gamma - \omega \qquad (2)$$

here ω is the amount going to waste in the pump. The lament current is then switched off and the pressure P in e gas-holder readjusted to give a second measured flow γ', ich that, with the setting of the variable throttle unaltered, the pressure p_B *is the same as when the filament was heated.* Under these conditions the flow to the pump will be the same as that during the oxidation. Hence ω is known, being equal to γ'.

The division of the apparatus by the fixed throttle into a high pressure part ($P \simeq 10$ cm of mercury) and a low pressure part ($p_B \simeq 1\ \mu$ of mercury) has the advantages that γ is unaffected by changes in the low pressure part, and is obtainable from easily measured quantities in the high pressure part of the apparatus.

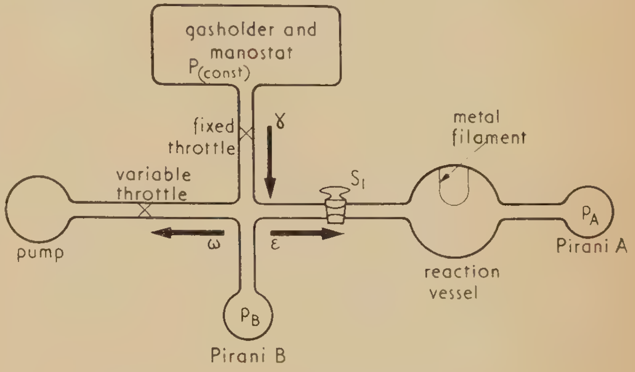

Fig. 1. Schematic diagram of apparatus

When it is desired to measure "small" oxidation rates a "closed volume" technique is used. A pair of settings of manostat pressure P and of the variable throttle are chosen which will produce both a total gas flow γ large compared with the expected oxidation rate ϵ and a suitable pressure p_A in the reaction vessel of volume V. When the filament is heated, p_A is not significantly decreased, as ω is nearly equal to γ. Hence, equation (2) cannot be used to calculate ϵ with any precision.

However, in this case, if stopcock $S1$ is closed for a few minutes in order to determine $V(dp_A/dt)$, p_A is not seriously diminished. Thus, a number of "spot" determinations of ϵ may be made during the course of a reaction which, as in the case of gold, lasts many hours. Stopcock $S1$ is closed for only a small fraction of the time and the total gas sorption evaluated by computing $\int_0^t \epsilon\, dt$.

Thus, when large rates have to be measured, isobaric conditions are ensured by the continuous flow technique provided η is constant. On the other hand, when rates are small, the use of closed volume technique entails only unimportant, short-duration departures from isobaric conditions.

Although specifically designed for oxidation studies, the apparatus also provides a convenient means of introducing a measured continuous flow of gas into any vacuum system.

THE APPARATUS

The apparatus is shown in more detail in Fig. 2; apart from the reaction vessel, it is made of Pyrex glass.

Pure oxygen is stored in a glass flask, the seal of which is broken by a magnetically operated soft-iron hammer. Stopcock $S4$ is used to fill the high pressure part of the apparatus (the gas-holder) to any desired pressure, measured by the difference in height of mercury in the manometer and adjacent barometer. Capillary connecting tubes are used in the gas-holder so that the greater part of its volume (of the order of 100 cm^3) consists of a 60 cm length of precision bore (1·131 cm^2 cross-section) Pyrex tubing (tube C). In order that the oxygen temperature may remain reasonably constant, in spite of laboratory temperature changes, tube C is enclosed in a massive copper box with a plate-glass front. The oxygen temperature is measured by a thermometer suspended in the box. Tube C is mounted vertically and closed at its lower end by a mercury surface (the "mercury piston") which can be raised, to reduce the volume of the gas-holder, by raising a mercury reservoir. The height of the mercury reservoir is controlled by a manostat (see Appendix) so as to maintain a constant oxygen pressure in the gas-holder, and the rate of rise of the "mercury piston" is observed on a vertical scale fixed behind tube C.

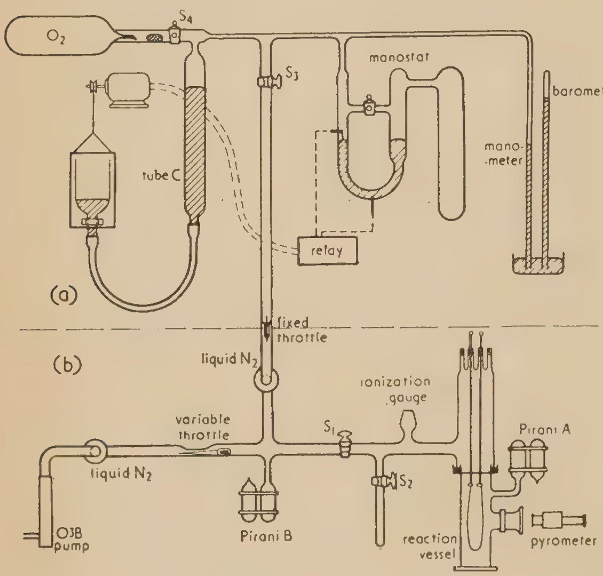

Fig. 2. General layout of apparatus

(*a*) High pressure part (gas holder). (*b*) Low pressure part.

The fixed throttle consists of a deliberately imperfect nickel-to-Pyrex "seal" and was constructed by collapsing a 5 cm length of narrow Pyrex tubing on to a bundle of six strands of $\frac{1}{4}$ mm nickel wire twisted together. A stopcock on the tube (not shown), bypassing the fixed throttle, can be opened whenever it is required to evacuate the gas-holder. After passing through the fixed throttle, the oxygen goes through a liquid-nitrogen cooled trap, to remove any trace of condensible impurities and to prevent mercury vapour entering the reaction vessel.

A hairpin filament of the metal under test (30–40 cm length) hangs vertically from gold-plated 8 s.w.g. high-conductivity copper leads which pass out through copper-to-Pyrex vacuum seals and are connected to a battery. Potential leads for resistance measurement are also provided.

Pyrex, transparent silica and gold-plated copper reaction vessels have been used. For ease of dismantling and reassembly, the joint between a glass reaction vessel and the rest of the apparatus is a waxed B55 cone and socket. In the case of the metal reaction vessel the cone is replaced by a water-cooled moat filled with vacuum wax. A Pyrex window, through which the filament can be viewed with an optical pyrometer, is waxed on to the end of one side arm on the metal reaction vessel. When temperature readings are not being taken, the window can be protected, by a magnetically-operated gold-plated steel shutter, from bombardment by hot oxygen molecules and from blackening if filament temperatures are high enough for evaporation. A Pirani gauge (Pirani *A*) is connected to a second side arm, and a liquid nitrogen trap and ionization gauge are mounted close to the reaction vessel. A closed system (volume approximately $2\frac{1}{2}$ l.) can be obtained by closing the stopcock *S*1 and s isolating the liquid nitrogen trap, ionization gauge, Pirani *A* and reaction vessel from the oxygen supply and the pump.

Surplus oxygen and impurities are removed from the system by a type O3B oil-diffusion pump (by Metropolitan Vickers Ltd.), the effective speed of which can be externally controlled by the magnetically operated variable throttle. A second Pirani gauge (Pirani *B*) is used to measure the pressure at the place where the gas flow γ splits into ϵ and ω.

The rate of oxygen flow from the gas-holder, *via* the fixed throttle, to the low pressure part of the apparatus is given by

$$\gamma = k\frac{293}{T}P\left(\frac{\partial V}{\partial t}\right)_{P.T.} \text{ mol./min} \qquad (3$$

where *P* mm of mercury is the pressure and T° K the temperature of the oxygen in the gas-holder, $(\partial V/\partial t)_{P.T.}$ cm^3/min the rate of volume change of the gas-holder and *k* the quantity of gas contained in 1 cm^3 at 1 mm of mercury and 20° C (or in 1 l. at 1 μ of mercury and 20° C). For a perfect gas $k = 3{\cdot}296 \times 10^{16}$ mol./μl.

EXAMPLE OF USE

The use of the apparatus and the continuous flow technique may be illustrated by the results of a typical titanium oxidation experiment. The filament consisted of a 32·5 cm length of about $\frac{1}{2}$ mm diameter "iodide" titanium wire. After correction for "cold-end" effect, the effective area of the filament was 5·202 cm^2.

The gold-plated copper reaction vessel was used and the system was pumped for a week to remove impurities, the vessel being heated to 90° C—a limit set by the waxed seal to the window. The gold-plated copper leads to the filament were also outgassed by heating to about 200° C by means of a small gold resistance furnace surrounding each lead. The overnight non-condensible desorption in the reaction vessel section (*S*1 closed: volume $2\frac{1}{2}$ l.) was found to be a convenient measure of the cleanness of the system. After about four or five days outgassing the overnight accumulation had fallen to about 1/25 μ of mercury; thereafter there was little further improvement.

The filament was first heated in a vacuum for a few minutes to a brightness temperature of 1175° C. The temperature was then lowered to the desired working value (brightness temperature 966° C) and the wattmeter reading required to maintain this temperature noted. Subsequently, throughout this particular experiment, the filament was always run at this power so that changes in brightness temperature could be ascribed to emissivity changes and hence changes in the state of the filament surface. Having found the "working watts" the filament was switched off and stopcock *S*1 closed to leave the filament in a vacuum while the oxygen pressure in the gas-holder and the variable throttle were set to values chosen in the light of previous experience. Stopcock *S*3 was then closed to stop the oxygen flow and the low pressure part of the apparatus was evacuated. After opening *S*1, setting the Pirani gauge zeros, by use of the ionization gauge, and switching on the filament at "working watts," the oxidation was started (at time $t = 0$) by opening stopcock *S*3.

Fig. 3 shows the variations of reaction pressure p_A and filament brightness temperature with time. For about 13 min, the reaction rate was fairly constant and the optical emissivity of the filament remained that of β-titanium in cuum. The appearance of oxygen-stabilized α-titanium on surface of the filament after about 13 min was shown by increase in reaction probability (lowering of p_A) and the ange in brightness temperature.

In order to calculate the reaction probability, it is necessary know the partial pressure of oxygen in the reaction vessel. is was obtained as follows. On simultaneously stopping oxygen supply and ceasing to remove impurities from the action vessel (i.e. closing stopcocks $S1$ and $S2$) the pressure the vessel rapidly fell to a small value (Fig. 3). This nimum residual value was interpreted as being the sum of steady partial pressure of impurities in the vessel while oxidation was proceeding and the build-up of impurity essure in the vessel since the closing of $S1$. Taking this nimum pressure as the impurity partial pressure in the action vessel during the run would lead to an over-estimate the impurity concentration, especially as likely impurities water vapour and hydrogen, from the dissociation of ter vapour, to both of which a Pirani gauge is 1·6 times sensitive as to oxygen. Conversely, taking the whole of rani A reading as oxygen leads to an underestimate of the purity concentration. Calculation of reaction probability m these two extremes provides limits inside which the rrect value of η must lie.

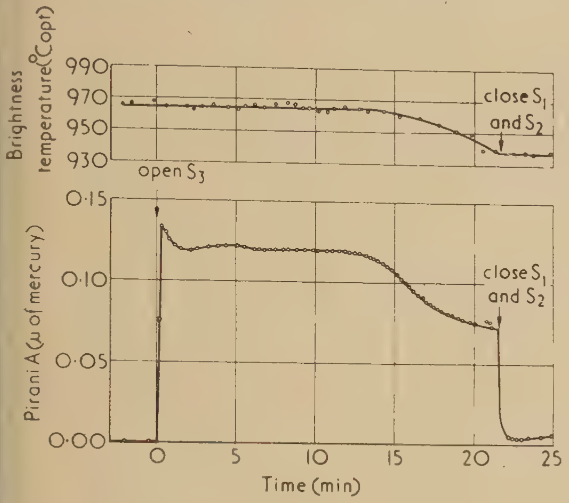

Fig. 3. Variation of filament brightness temperature and reaction vessel pressure during titanium oxidation

The oxidation having been completed, ω was determined the method described above. The adjustment of γ' to tain exactly the same Pirani B reading was too time-nsuming, but it sufficed to repeat p_B approximately and to ply a small correction for the deviation from the exact ting.

The numerical data for this experiment were as follows.

	P (mm Hg)	T (°K)	dV/dt (cm³/min)	γ (μl./min)
uring oxidation	222·8	293·2	0·499	111·0
uring determination of ω	71·1	293·1	0·323	23·0

ie small correction term for non-reproduction of p_B was 1 μl./min. Hence from equation (2)

$$\epsilon = 111\cdot0 - (23\cdot0 + 0\cdot1) = 87\cdot9\ \mu\text{l./min}$$
$$\epsilon/A = 0\cdot929 \times 10^{16}\ \text{mol.cm}^{-2}\,\text{s}^{-1}$$

For pressures expressed in microns of mercury, the oxygen pingement rate is given by

$$\beta = (6\cdot210 \times 10^{18})\, p_A/(\text{T}^\circ\text{K})^{\frac{1}{2}}\ \text{mol. cm}^{-2}\,\text{s}^{-1} \qquad (4)$$

The mean reaction vessel temperature was 14·8° C, which was taken to be the incident oxygen temperature, since the mean free path was greater than the vessel diameter. The constant reaction pressure and the minimum residual pressure (Fig. 3) were 0·1209 and 0·0044 μ of mercury respectively. Hence the maximum and minimum oxygen partial pressures were 0·1209 and 0·1165 μ of mercury leading to a β_{max} of $4\cdot42 \times 10^{16}$ and a β_{min} of $4\cdot26 \times 10^{16}$ mol. cm^{-2} s^{-1}.

Hence from equation (1), η was between 21·0 and 21·8%.

DISCUSSION OF PERFORMANCE

When the apparatus is used to measure "large" rates, changes in reaction probability produce changes in p_A (Fig. 3). An expression for the sensitivity with which changes in η can be deduced is obtained as follows.

The equations for the gas flows in the apparatus are

$$\gamma = \epsilon + \omega$$
$$p_B - p_A = \epsilon Z$$
$$p_B = \omega R$$

where Z and R denote the impedances encountered by the gas flows ϵ and ω respectively (Fig. 1) and the pressure at the pump is assumed negligible compared with p_B. Substituting from these equations in equation (1), the reaction probability is given by

$$\eta = (\gamma R - p_A)/Ab(R+Z)p_A$$

Differentiating with respect to p_A, with γ held constant, it follows that

$$-\frac{d\eta}{dp_A} = \frac{\gamma R}{Ab(R+Z)p_A^2}$$

where, for the purpose of obtaining an expression for sensitivity, the small dependence of R and Z on pressure may be neglected. Hence

$$-\frac{d\ln\eta}{d\ln p_A} = -\frac{p_A}{\eta}\cdot\frac{d\eta}{dp_A} = 1 + \frac{p_A}{\epsilon(R+Z)} \qquad (5)$$

The ratio p_A/ϵ is fixed by the state of the filament surface [equation (1)], so that if it is desired to work at a certain reaction pressure the only control on the sensitivity is to vary $(R+Z)$. For high sensitivity the impedance $(R+Z)$ should be made large.

On the other hand, in order to minimize the uncertainties in η mentioned in the last section, it is desirable to keep the partial pressure of impurities in the reaction vessel as low as possible. This means that if non-condensible impurities are continuously produced by the walls of the vessel and removed by the pump it is desirable to make $(R+Z)$ as small as possible. Effective pumping of *condensible* impurities, *via* a low impedance pumpline, is obtained by having a liquid-nitrogen trap close to the reaction vessel.

The two requirements regarding the magnitude of $(R+Z)$ are contradictory. Consider the implications of typical compromise values used in the present apparatus. The impedance Z is about $\frac{1}{2} \times 10^{-2}$ min/l. and typical values for R, p_A and ϵ are 2×10^{-2} min/l., 0·1 μ and 100 μl./min respectively. Putting these values in equation (5)

$$\frac{d\ln\eta}{d\ln p_A} = 1 + \frac{0\cdot1}{100\,(2\cdot5\times10^{-2})} = 1 + \frac{1}{25}$$

that is, an apparatus sensitivity which is only about 4% less than the maximum which would be obtained if $(R+Z)$ were infinite.

It remains to discuss whether these values of $R + Z$ are low enough from the point of view of impurity accumulation. The observed overnight desorption of non-condensible gas is a useful empirical indication of the cleanness of the system. It does not, however, provide a measure of the total impurity production rate in the reaction vessel *during oxidation*, when the leads to the filament are heated by conduction and might desorb, despite their outgas period at 200° C, and there is the possibility of bombardment of the vessel walls by hot gas molecules rebounding from the heated filament. Fig. 3 shows that after the minimum pressure ($S1$ and $S2$ closed) had been reached there was a pressure increase of about $0 \cdot 1\ \mu$/h. Since the system volume was $2\frac{1}{2}$ l., this observed pressure increase corresponds to an impurity production rate of $0 \cdot 25\ \mu$/h, which is negligible when compared with reaction rates of the order of $10^2\ \mu$l./min. However, even if this impurity were all non-condensible, the use of the continuous flow technique would only lead to a steady impurity pressure in the reaction vessel of

$$(0 \cdot 25/60)\,(2 \cdot 5 \times 10^{-2}) \simeq 10^{-4}\ \mu \text{ of mercury.}$$

With reaction vessel pressures of about $10^{-1}\ \mu$ of mercury, this would lead to an error of about $0 \cdot 1\%$ in reaction probability if no correction were applied.

In the discussion of the results of the titanium experiment above, the uncertainty in η is seen to be about 4%. This is probably caused by the lag of Pirani A, since a simple calculation shows that, after closing $S1$ and $S2$, the oxygen pressure should fall to 1% of its initial value in about a quarter of a second, whereas the indicated pressure minimum (Fig. 3) occurs after seventy-five seconds. Thus, the correct value of η probably lies close to the higher of the two calculated values.

This uncertainty in the partial pressure of impurities is a source of possible systematic error in the results. As regards random experimental errors, however, it is estimated that ϵ is unlikely to be wrong by more than 4%, derived about equally from measurements of flow rates and from estimates, based on the appearance of the oxidized filament, of the cold-end effect. Reaction vessel pressures are considered to have about the same accuracy, the main source of error being zero-drift of the Pirani gauges.

When using the closed volume technique for measuring "small" rates the accumulation of impurities in the reaction vessel again leads to uncertainties in bombardment rate and also to errors in ϵ, since the observed $-dp_A/dt$ is the net effect of oxygen disappearance from the gas phase and desorption of non-condensible impurities. It is therefore particularly necessary, when using this technique, adequately to degas the reaction vessel and leads before the start of an experiment.

ACKNOWLEDGEMENT

The authors wish to thank Mr. T. V. Vernon for his help with the manostat circuit.

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APPENDIX

The manostat

The construction of the manostat, designed to maintain a constant pressure in the gas-holder, is shown in Fig. 2. In essence, it consists of a U-tube of mercury which is made to close an electrical circuit whenever there is a difference between the levels of the mercury in the two limbs. The electrodes are tungsten wires sealed through the Pyrex walls of the U-tube.

Gas at the desired pressure is trapped in the volume above the mercury surface in the right-hand limb of the U-tube. When the pressure of oxygen in the gas-holder (i.e. the gas pressure in the left-hand limb) falls below this reference pressure, the difference in levels closes the switch and starts a small electric motor. The motor raises the mercury reservoir and, hence, the level of the mercury piston in tube C. This reduces the volume of the gas-holder until its pressure is again equal to the reference pressure, when the difference between the mercury levels in the U-tube being again zero, the mercury switch is opened.

The mercury switch's make-and-break operation involves about $\frac{1}{4}$ mm movement of the mercury level in the left-hand limb. In order to minimize the corresponding movement of the mercury level in the right-hand limb, which causes a change in the reference pressure, the diameter of the right-hand limb is about three times that of the left-hand limb. Also, to reduce the effect of volume changes on the reference pressure, the volume of the trapped gas is made large.

Taking laboratory temperature as 300° K, the reference pressure will change by 1% for a change of 3° in the temperature of the right-hand limb, since the trapped volume acts as a constant volume gas thermometer. It is, therefore, enclosed in a massive copper box to minimize the effects of change of laboratory temperature.

The current to be broken by the mercury switch is limited to less than 10 μA, to minimize arcing and consequent contamination, by using a simple electronic circuit (Fig. 4) working directly off the a.c. mains. The "break" action of the mercury switch is arranged to trigger a thyratron, which in turn activates a Post Office relay. When energized, the relay breaks the electric current to a small 24 V d.c. motor used for raising the mercury reservoir. The motor is fitted with a worm reduction gear and further speed reduction is obtained *via* a sprocket and chain drive using instrument chain (pitch 0·110 in.) supplied by the British Machine Chain Co. Ltd. By varying the voltages applied to the armature and field windings of the motor its speed can be set to any desired value.

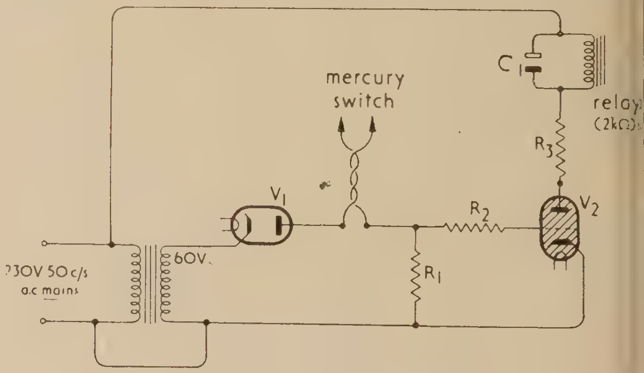

Fig. 4. Circuit of manostat

$R_1 = 8 \cdot 2$ MΩ
$R_2 = 10$ kΩ
$R_3 = 2 \cdot 2$ kΩ, 15 W
$C_1 = 2\ \mu$F, 100 V
V_1 = CV140
V_2 = 2D21

n extensometer microscope stage for photoelastic studies in rubber

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[*Paper received* 19 *October*, 1956]

The instrument described is designed for attachment to the stage of a polarizing microscope in place of the conventional mechanical stage. Its purpose is to permit the use of a special compensator technique to determine stress distribution at the tip of a tear in an extended sheet of rubber.

Examples are given of the stress distribution, both in magnitude and direction, at the tip of a tear in pre-vulcanized latex sheet, and the relative behaviours of the two principal stresses briefly discussed.

e photoelastic measurement of stress in loaded bodies of ably stress-birefringent materials has been highly developed ecent years. In most cases, such measurements rely upon inear relation between optical retardation and stress and fact that stress concentration does not cause appreciable ormation of the body. In a material such as natural rubber, wever, these two conditions no longer apply, the former ing on account of strain-induced crystallization and the er because of the low elastic modulus.

This paper is concerned with the determination of stresses und the tip of a tear in a stretched sheet of rubber, and s problem has two important features which arise from special nature of the material. Firstly, the high extensi- ity of the rubber limits the region of high stress concentra- n to very small linear dimensions, of the order of 0·1– 2 mm in a typical case. Secondly, the changes in sheet ckness across this region, together with non-linear stress- efringence at high extension, demand a more refined hnique than simple observation of the isochromatic nges. Fortunately such a technique is available in the use a compensator cut from the same sheet of rubber as is the t piece itself, and it is possible by this means to eliminate ost of the difficulties encountered with more conventional ethods.

These considerations led to the design of the instrument cussed in this paper, which, like the fibre extensometer eviously described by the author,(1) is designed for attach- ent to the stage of a polarizing microscope.

CONSTRUCTION

The extensometer stage is essentially a device for stretching o thin sheets of rubber in mutually perpendicular directions. The planes of the two sheets lie parallel to each other and normal to the incident polarized beam. Each rubber sheet is held between two parallel clamps which slide smoothly along runner bars extending the length of the frame. This is illustrated in Fig. 1. The upper pair of clamps are 11 cm and the lower pair 5 cm in length, being designed to take differently shaped test pieces as shown in Fig. 2. The upper, or "pure shear"(2) test piece contains a cut or tear, at the tip of which the stress concentration is to be studied, whilst the lower test piece is used in simple extension.

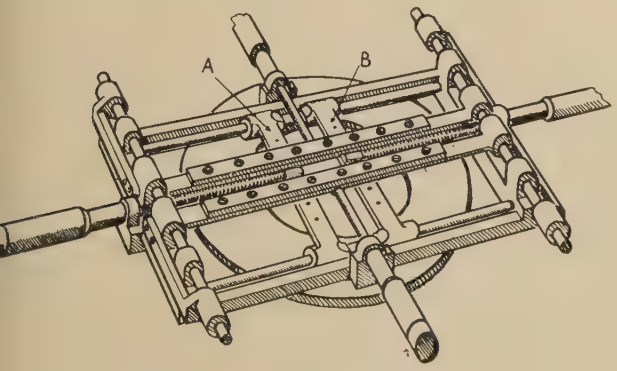

Fig. 1. The extensometer

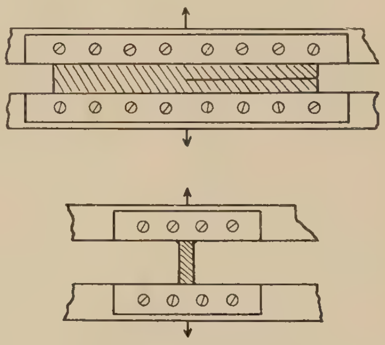

Fig. 2. The clamps holding differently shaped test-pieces

The clamps are driven by four independent micrometer screws of pitch 1 mm, their displacements being measured in the usual way. The calibration is such that the separation of a pair of clamps is given directly by adding the readings on their respective micrometers. The method adopted for securing the rubber sheets, which are some 0·2 mm in thickness, is shown in Fig. 3. Each clamp consists of a crosshead and a detachable bar, which is fastened to the crosshead by a number of screws to give uniform clamping pressure along

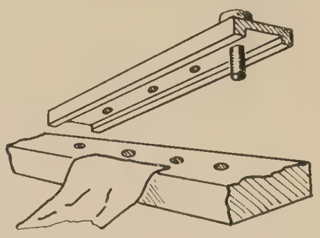

Fig. 3. Method used to secure rubber sheets in the clamps

its length. Whilst the crosshead surface is flat, the underside of the bar has been milled away so that contact occurs only over a narrow strip along each side of the bar. Its success in preventing slip is due partially to the higher pressure resulting from decreased area of contact, and partially to a more uniform distribution of pressure arising from flexure of the bar.

Each pair of clamps has a minimum separation of 1·0 cm, to avoid them fouling the microscope objective at low extensions of the test piece. The upper pair open to a maximum separation of 4·2 cm and the lower to one of 9·0 cm.

The rectangular frame of the extensometer stage is bolted to an annular plate of internal diameter 6·4 cm. This plate fits into the stage of a polarizing microscope (by Bausch and Lomb Optical Co., U.S.A.) in place of the centring mechanical stage supplied by the makers. The centring mechanism thus operates on the instrument and provides the small but necessary field of view adjustment. The extensometer may also be rotated so that the micrometer barrels lie free of the body of the microscope.

STRESS IN THE EXTENDED TEST PIECES

In the investigation of stress concentration at the tip of a tear, the test pieces used are as shown in Fig. 2. These are cut from the same sheet of rubber, the tear tip having been formed first and the "pure-shear" test piece, some 8 or 9 cm by 1·4 cm, marked out around it. The simple extension test piece is approximately 2·0 by 0·4 cm. The state of strain of the "pure-shear" test piece is completely defined by the extension ratio λ applied to it, this ratio being given directly by the micrometer readings. In the case of the simple extension test piece, however, the nominal value of λ must be corrected for end effects. Errors in λ at high extension could lead to serious miscalculation of stress if this were obtained from independent stress-strain data. For this reason, as well as to obviate stress-relaxation effects, it was felt advisable to incorporate some direct means of measuring tension in the lower test piece. The value of λ is still required, of course, for the stress to be known, but it now enters only as a multiplying factor.

The tension measurement is made using a calibrated coiled spring, one end of which is attached *via* a small clamp to the test piece and the other to one of the micrometer crossheads *A*. The other end of the test piece is held as usual by the opposite crosshead clamp *B*. The small subsidiary clamp carries a thin pointer which is alined with a similar pointer cemented to the frame of the instrument. By keeping the pointer at its null position the extensions of the spring and the test piece may be read directly from micrometers *A* and *B* respectively.

COMPENSATOR TECHNIQUE FOR MEASUREMENT OF STRESS

The state of strain in any small element of the sheet near the extended tip is completely determined by two principal stresses, assuming the stress perpendicular to the sheet to be zero. The optical retardation of the sheet at that point is

$$r = t \cdot \Delta n \qquad (1)$$

where t is the thickness of the deformed rubber and Δn the stress birefringence. Since both t and Δn are functions of th principal stresses, P and Q, this may be written

$$r = f(P, Q) \qquad (2$$

Assuming that the rubber is essentially in simple extension as is the case near the free edge of the tip, we have $P = 0$ an

$$r = f(Q) \qquad (3$$

If, therefore, a second identical sheet of rubber is subjecte to simple extension in a direction perpendicular to that of th element considered, and introduced into the incident beam extinction will occur when the known value of Q in thi "compensator" equals that in the element.

This is the principle upon which the present compensatio method is based. In addition to bypassing the difficulties o large deformation and non-linear stress-birefringence, th method also avoids dispersion errors which often arise wher compensators of different materials are used. The onl complication occurs when the state of strain in the test piec departs from simple extension, for then the thickness compensation is no longer complete. When this happens it i possible to obtain a solution by determination of the separat stresses, application of a thickness correction and successiv approximation, but a discussion of this lies beyond the sco of the present paper.

EXPERIMENTAL PROCEDURE AND RESULTS

The extensometer, with only the upper test piece mounted is fixed in position on the microscope and centred to brin the tear tip into the field of view. The specimen is th extended to the desired amount and the adjustable condens system of the microscope set to give a nearly parallel beam of light. The apparatus is now ready for photographi record to be made of the isoclinic fringes which appear a different positions as the crossed polarizer and analyser a rotated together. Using a 35 mm strip film camera with side viewing tube, the fringes are photographed at each fresh rotation through a known angle, usually 2° or 5° according to the sensitivity of the fringe pattern to such rotation. A low-power objective giving a comparatively large field o view is best for this part of the investigation.

When the isoclinics have been photographed, the extensometer is removed from the microscope in order to moun

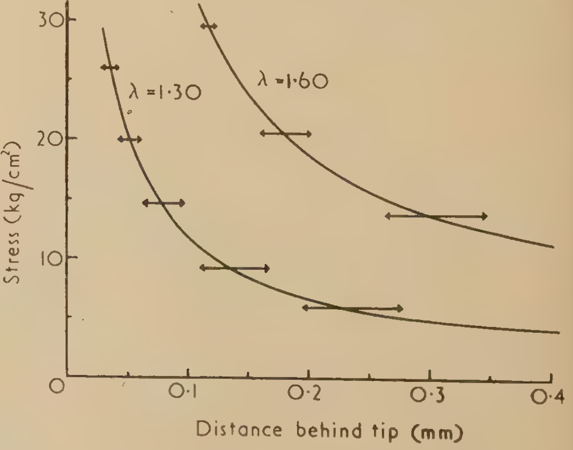

Fig. 4. Stress concentration curves at different extensions of the test-piece

simple extension test piece. As this compensator test ce is extended a black fringe appears behind the tip in tear test piece. Using an eyepiece scale its position and th are recorded as functions of the compensator extension

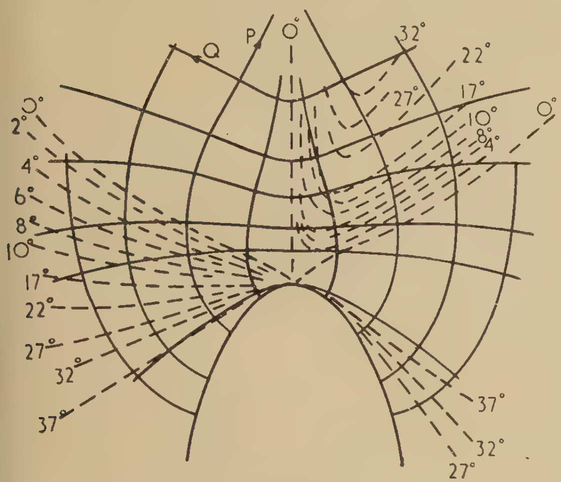

Fig. 5. Isoclinics (shown dotted) and lines of principal stress at $\lambda = 1{\cdot}10$. Magnification ×35

l tension, measured as already described. From this data raph of principal stress difference against distance behind tear tip may be readily obtained. In plotting this curve s assumed that each edge of the black fringe represents a

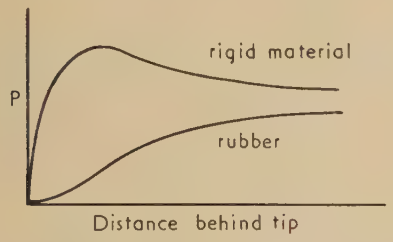

Fig. 6. Behaviour of the minor principal stress *P*

iation from the nominal stress of the same magnitude ugh, of course, of opposite sign. This enables the curve be well defined even in regions where the black fringe is fuse. Fig. 4 illustrates this for two different extensions of a tear test-piece of pre-vulcanized latex, to which material the results given below also refer.

The isoclinic patterns obtained photographically are superimposed by sketching in the projected images on a large sheet of graph paper, an epidiascope (by Aldis Bros., Ltd.) being used for this purpose. From the completed map the lines of principal stress are deduced, as shown in Fig. 5. The behaviour of these lines may be used in conjunction with the curve of principal stress difference to calculate the separate stresses using the Lamé–Maxwell equation.(3) Such a calculation suggests (*a*) that the stress component perpendicular to the direction of stretch rises slowly from zero to its value in the body of the test-piece and (*b*) that its magnitude is such that a considerable region near the tip is essentially in simple extension. This behaviour is sketched in Fig. 6 and is in contrast to that found(4) under similar circumstances in a rigid material.

CONCLUSION

The instrument and techniques described have made it possible to solve, to a good degree of completeness, the stress distribution around a tear tip in a rubber sheet. The methods employed should be of general application to materials in which deformability and non-linear stress birefringence exclude the usual stress-optical approach. The instrument should also find application in more general fields such as the comparison, by optical compensation, of stress-birefringence in simple extension, pure shear and other more complicated states of strain.

ACKNOWLEDGEMENTS

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A system for controlled linear cooling of laboratory furnaces

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[*Paper received* 14 *November*, 1956]

A synchronously-driven resistance bridge network has been developed which, when used with a suitable proportioning temperature controller will control linearly the heating or cooling of a small laboratory furnace within the range 6 to $\frac{1}{12}$° C/min. The theory and design of the unit are described.

The thermal treatment of alloy steels depends essentially on the reversion of the austenitic phase to duplex ferrite and carbide structures, during cooling from a high temperature. This change of phase exhibits a very marked and rather complex hysteresis and the properties of the steel, notably the hardness and tensile strength, can be profoundly altered by changes in the rate of cooling.

In order to simulate in the laboratory the cooling of ingots and comparatively large forgings, between the extremes of oil-quenching and full-annealing, means are required for controlling the cooling of specimens between about 50 and $\frac{1}{12}$° C/min. Experience with a laboratory furnace supplied with current from a motorized and cam-corrected variable transformer, showed this simple device to be effectively linear in its response between rates of cooling of 50 and 6° C/min. At lower rates, however, the desired linear control was lost and the effect of electrical fluctuations in the mains supply became significant.

A system of controlled cooling in which the previous objections are obviated and temperature is linearly related to time within the range 6 to $\frac{1}{12}$° C/min has been developed by motorizing a proportioning "on-off" a.c. bridge temperature controller, with a platinum resistance thermometer as the temperature-sensitive element. This system has proved to be effective in combating fluctuations in the mains supply and produces a consistent and steadily falling, or rising, temperature.

A convenient starting-point for the control unit was an existing resistance thermometer controller type R.T. 1 (by Sunvic Controls Ltd.), but the principles of its modification could readily be applied to the more recent Sunvic model R.T. 2, or to the Prosser controller, the constructional details of which have been described elsewhere.* Under normal operating conditions, each of these instruments effects an automatic comparison of the resistance of a platinum thermometer, placed in the furnace, with that of a pre-set master resistor and utilizes an off-balance signal to control proportionally the input of power to the furnace. If, on the other hand, the master resistor be altered, then the controller will operate to restore balance by a readjustment of input power, and hence temperature, of the furnace. On this basis, a scheme has been developed for motorizing a suitably compensated master resistor in a manner such that a definite and, in particular, linear time-temperature programme is impressed on the furnace. Subject to the availability of suitable resistors, or methods of compensation, more complex thermal programmes may readily be obtained.

It may appear that the instrument performs no more useful function than that of a normal cam-operated programme controller with galvanometric balancing. Experience with instruments of the latter type shows, however, that they tend, when used with small laboratory furnaces, to exaggerate small errors in the profile of the cam and to impress on the cooling-curve an objectionable sawtooth wave-form arisin largely from the relatively low sensitivity of the necessaril robust chopper bar mechanism. With careful choice of th more important components of a resistance thermomete bridge unit and the use of a fully proportioning controlle the sawtooth wave-form may be considerably reduced an often removed completely.

THEORY OF OPERATION

For a platinum resistance thermometer, the variation c resistance with temperature is described by the law:

$$R_t = R_0(1 + \alpha t + \beta t^2) \cdot$$

where R_t = resistance at temperature t° C,
R_0 = resistance at 0° C,
$\alpha = +0{\cdot}003\,976\,5$,
and $\beta = -0{\cdot}000\,000\,585$.

(*Note*.—The values of α and β are those published b Johnson–Matthey and Co. Ltd., and relate to J.M.C Thermopure platinum, manufactured for this type of service

Bearing in mind that the immediate intention is to achiev linear cooling, it becomes necessary to devise an electro mechanical instrument, the resistance of which will vary wit time according to the above law. The linear portion $R_t = R_0(1 + \alpha t)$ of equation (1) can be obtained easily an accurately by motorizing a ten-turn helical potentiometer i series with a fixed resistor, a synchronous motor bein preferable for the drive. Greater difficulty attends th generation of the square-law term, but this is a second-orde

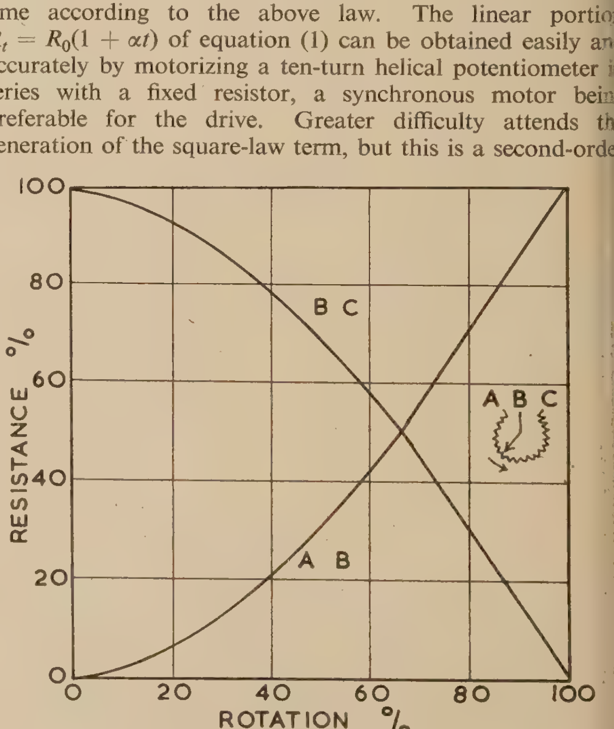

Fig. 1. Characteristics of semi-log wire-wound potentiometer

rection and it has been found that a driven, semi-arithmic, wire-wound potentiometer gives a sufficiently se approximation for most practical purposes. The aracteristics of an actual potentiometer are shown in Fig. 1, ilst Fig. 2 shows schematically the complete resistance work.

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* Prosser, L. E. *Engineering*, **148**, p. 95 (1939).

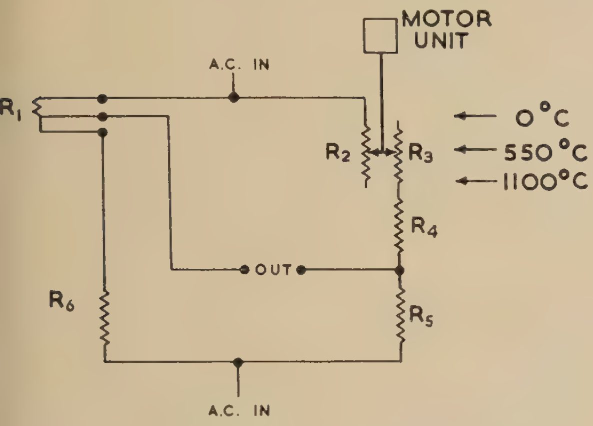


Fig. 2. Circuit of motorized resistance bridge

The present apparatus was designed to operate within the mperature range 0 to 1100° C, which implies a variation in sistance of the platinum resistance thermometer (R_1 in g. 2) from 10·0 Ω at 0° C to a maximum of 46·66 Ω at 00° C. For convenience the value of the helical potentio-eter R_2 was fixed at 100 Ω. Under these circumstances a itable value for the resistance R_6 is 30·0 Ω.

Corresponding values for the remaining resistors R_3, R_4 d R_5 can be determined by a simultaneous solution of the nditions of the resistance network at three temperatures, eferably the two extremes (0 and 1100° C) and the mean mperature (550° C). The values of individual components arms of the resistance bridge at these three temperatures e listed in Table 1.

ible 1. *Values of the bridge arms at different temperatures*

mperature (°C)	*Arm A* Platinum resistance thermometer (Ω)	*Arm B* $R_2 + R_3 + R_4$ (Ω)	*Arm C* R_5 (Ω)	*Arm D* R_6 (Ω)
0	10·00	$0 + R_3 + R_4$	R_5	30·0
550	30·10	$50 + 0·7R_3 + R_4$	R_5	30·0
1100	46·66	$100 + 0 + R_4$	R_5	30·0

rom the conditions of the bridge at 0 and 550° C we obtain:

$$\frac{10·00}{30·10} = \frac{0 + R_3 + R_4}{50 + 0·7R_3 + R_4} \qquad (2)$$

d between 0 and 1100° C:

$$\frac{10·00}{46·66} = \frac{0 + R_3 + R_4}{100 + 0 + R_4} \qquad (3)$$

lving equations (2) and (3) gives:

$$R_3 = 19·45\ \Omega \quad \text{and} \quad R_4 = 2·52\ \Omega$$

t any particular temperature:

$$\frac{R_1}{R_6} = \frac{R_2 + R_3 + R_4}{R_5} \qquad (4)$$

nce

$$R_5 = 65·90\ \Omega$$

A potentiometer having the precise value calculated for R_3 (19·45 Ω) cannot readily be obtained, but R_3 serves only to introduce a correction factor and a potentiometer of 5% tolerance with a value of 20 Ω will usually suffice. It has been found advantageous in practice to construct R_3 from two 40 Ω potentiometers connected in parallel, when the "stepping" effect of the wipers rubbing over the rather coarse turns of the windings is considerably reduced.

Using the characteristic curves of the semi-logarithmic potentiometer, as shown in Fig. 2, and assuming correct mechanical coupling between the driven components, an estimate can be made of the errors to be expected from the bridge. The relationship between certain calculated data and the rotation of the potentiometers using a 20 Ω potentiometer for R_3, is shown in Table 2. These data show the bridge to be capable of a close approach to linearity of temperature with time between room temperature and about 800° C. Above this temperature the deviation increases, displaying a maximum departure from linearity of 7° C at a temperature of 1000° C. The significance of this deviation will depend upon the circumstances of application.

Table 2. *Calculated data showing temperature errors*

Rotation (%)	R_2 (Ω)	R_3 (Ω)	$R_2 + R_3 + R_4$ (Ω)	*Equivalent platinum resistance* (Ω)	*Equivalent temperature* (°C)	*Linear temperature* (°C)	*Error* (°C)
0	0	19·45	21·92	10·00	0	0	0
10	10·0	18·86	31·39	14·29	110	110	0
20	20·0	17·89	40·42	18·40	219	220	−1
30	30·0	16·84	49·37	22·48	330	330	0
40	40·0	57·99	57·99	26·40	441	440	+1
50	50·0	13·62	66·15	30·12	550	550	0
60	60·0	11·44	73·97	33·68	659	660	−1
70	70·0	8·75	81·28	37·01	766	770	−4
80	80·0	5·83	88·36	40·23	872	880	−8
90	90·0	2·92	95·45	43·46	990	990	−6
100	100·0	0	102·53	46·69	1100	1100	0

CONSTRUCTION OF UNIT

When planning the construction of the apparatus, consideration was given to the intended application to metallurgical problems. The nature of these problems was such that the instrument would rarely be required to operate over the full range of temperature from 0 to 1100° C. On the other hand, regular use of a portion only of the available potentiometric range appeared to constitute an unnecessary sacrifice of mechanical accuracy. Provision was therefore made for the relevant components of the bridge network to be readily interchangeable, in a manner such that the maximum rotation of the potentiometers would be utilized for each particular application. A schematic diagram of the various units is shown in Fig. 3, and a photograph of the complete apparatus is reproduced in Fig. 4.

The synchronous motor (*M*, Fig. 3) drives through a spur gear *G*1 on to one of a pair of contrate gears *G*2, *G*3 on a spindle connected to the helical potentiometer *R*2. The use of a spur gear and two contrate gears facilitates reversal from controlled heating to controlled cooling, whilst in the neutral position a handle *K* allows manual adjustments to be made without disturbing the motor.

The maximum rotation of the pair of 40 Ω potentiometers ($R_{3a,b}$) is limited by their construction to about 270°, whilst that of the helical potentiometer R_2 is 10 × 360°. This would entail a mechanical coupling with a calculated ratio of 13·3 : 1. In practice, the more convenient ratio of 15 : 1 has proved satisfactory and is derived from two trains of gears, giving a primary reduction of 5 : 1 (*G*4, *G*5) and a secondary reduction of 3 : 1 (*G*6, *G*7). The two 40 Ω potentiometers, which together form R_3, are coupled by spur gears having a 1 : 1 ratio (*G*8, *G*9). Each of the driving spindles is mounted through brass bushes *B* attached to brackets on the main frame, which is constructed from 16 s.w.g. sheet aluminium. In order to reduce frictional forces, those spindles which pass through three bearings have been split and re-connected with radio-type universal couplings *F*. Electrical connexions to the chassis are made by means of standard plugs and sockets.

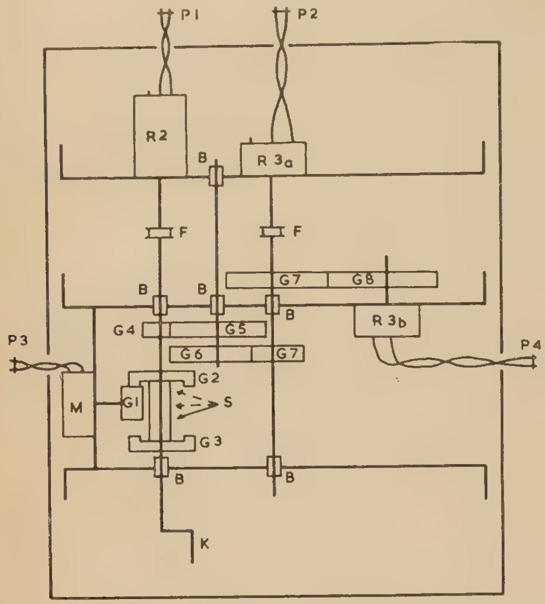


Fig. 3. Schematic diagram of mechanical layout of the control unit

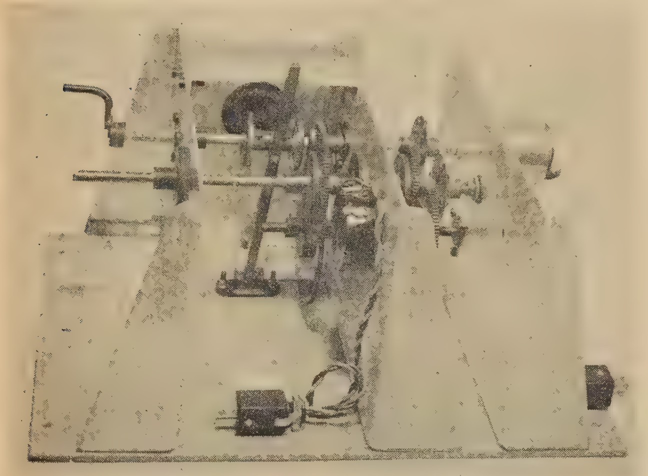


Fig. 4. Control unit for linear cooling

The values of the two resistors R_4 and R_5 depend on the range of temperature which is to be covered and these components have been mounted on a multi-pin plug to facilitate changing. The section of the control unit shown in Fig. 4, comprising the moving parts of the bridge network, is connected by the plugs P1 to P4 to the appropriate stationary portions of the network, which are mounted on a permanent rack together with the ancillary furnace controls.

PERFORMANCE

Experience with the completed unit showed its performance to fulfil expectation in most respects. A portion of a typical record of time and temperature, obtained with a Brown Electronik temperature recorder, during cooling from 1000° C to room temperature in about twenty hours, is shown in Fig. 5. Adventitious electrical fluctuations in the mains supply are effectively suppressed and a detailed examination of the recording shows that the "best" line drawn through the recorded points does not depart by more than ±1° C from linearity with time over the range 950 to 225° C. A similar order of accuracy has been observed with rates of cooling from 6 to $\frac{1}{12}$° C/min.

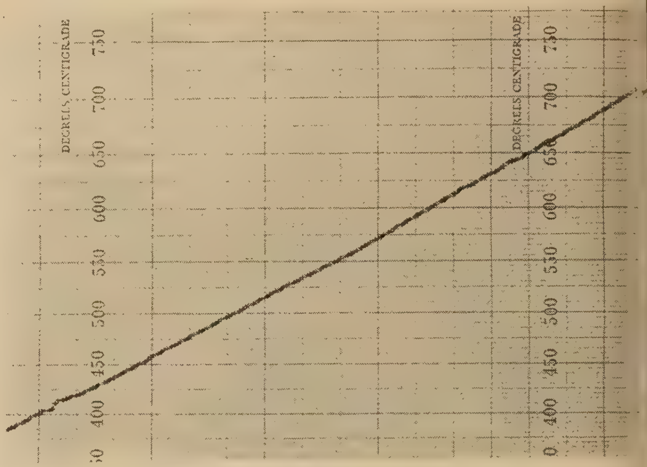


Fig. 5. Example of time-temperature record

Using "on-off" control of the power supply, the proportioning action of the controller tended to be swamped at the lower end of the temperature range. A ready correction was effected during operation by periodically reducing the voltage across the furnace to values more consistent with the progressively falling temperature. Alternatively, a ring-switch and fixed resistors may be included in the motorized assembly, to supply power to the furnace in perhaps four increments.

When cooling at the lower rates it was found essential first to spread the lubricant film evenly on the potentiometers by repeated manual operation over their full range. Otherwise slight contact troubles between successive turns of the windings interfered with the correct cycling of the proportioning controller, causing temporary departures from the desired cooling curve. This effect will be seen as a kink at 410° C in the record shown in Fig. 5.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to various colleagues who have helped with this work, in particular to Mr. E. W. Colbeck, Metallurgical Director, for permission to publish this paper and to Dr. J. R. Rait for his continued interest and encouragement.

Laboratory and workshop notes

Bakeable high vacuum seals

By N. W. Robinson, Mullard Research Laboratories,
Salfords, Surrey

[*Note received* 13 *November*, 1956]

etal seals for high-vacuum demountable apparatus are cessary where high temperatures are required. The con- ntional metal seal requires that at least one of the surfaces be sealed has on it a raised portion triangular in section iich compresses a soft metal washer.

A form of all-metal seal is shown in Fig. 1(*a*) which allows ane flanges to be joined with a seal which can be baked peatedly to temperatures of 450° C and cooled without ıking.

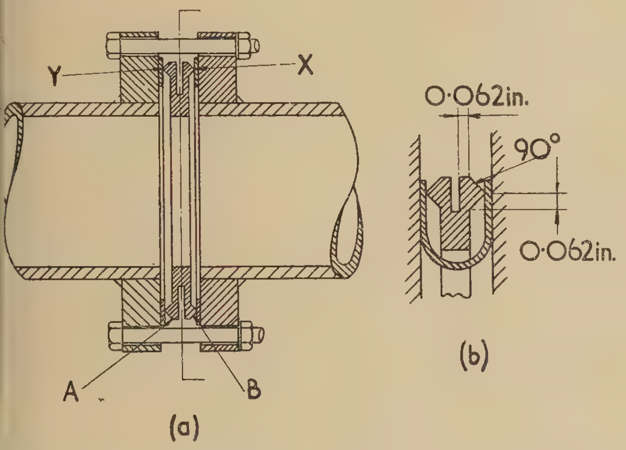


Fig. 1. (*a*) Ring seal for joining two flat flanges. (*b*) Modification with spun washer and only two sealing surfaces

The seal is made between two copper washers (*X*, *Y*) 010 in. thick, which are clamped between the flanges by steel ring on which two annular knife edges (*A*, *B*) are rned. Equidistant between the knife edges is a groove cut to the periphery of the ring to a depth which imparts a ntilever action to the knife edges when they are bolted gether. The stiffness of the knife-edge system must be fficient to cause plastic deformation of the copper when e flanges are bolted together cold and still exert a positive rce on the copper both during the annealing, which occurs ı baking, and the subsequent cooling.

A modification shown in Fig. 1(*b*) shows that the two flat pper washers may be replaced by one U-shaped washer and the number of sealing surfaces halved. Suitable dimensions are given in the figure for a mild steel ring 4 in. in diameter. This form of seal may be used with rectangular shaped flanges, or it may be used on large industrial valves which have replaceable cathodes.

The same method may be applied to joining two small diameter pump lines, as shown in Fig. 2(*a*). Here there is only one knife edge and the stiffness is reduced by a peripheral slot a short axial distance from the clamping surface. Fig. 2(*b*) shows a modification suitable when copper tubes are joined. The copper tube is spun over one flange to form its own washer leaving only one sealing surface on which leaks could occur.

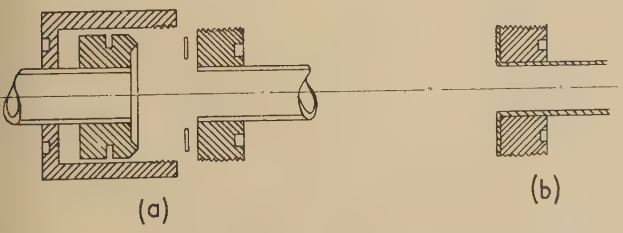


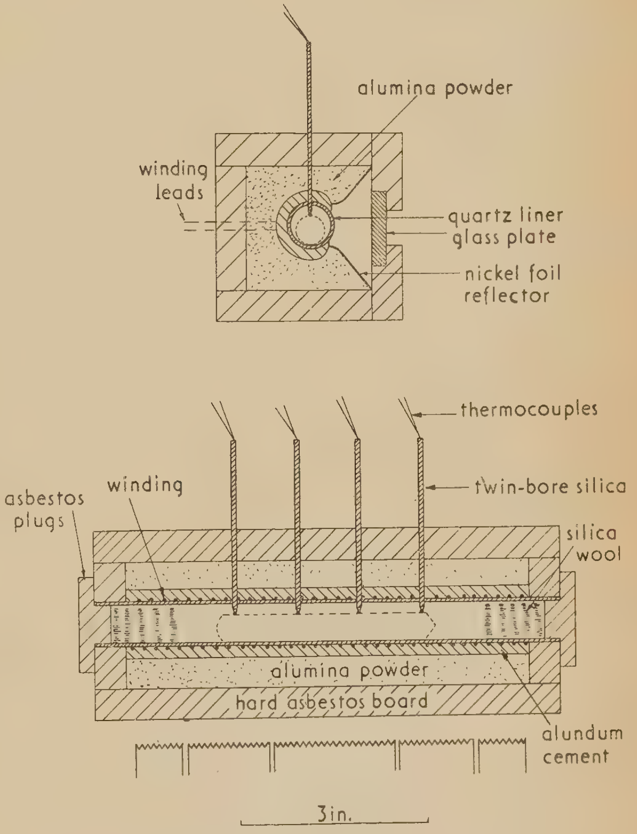
Fig. 2. (*a*) Method of joining two tubes. (*b*) Modification using an open copper tube and resulting in only one sealing surface

A direct-vision crystal growth furnace

By D. F. Gibbs, B.Sc., A.Inst.P., H. F. Kay, M.Sc., Ph.D., A.Inst.P., and M. A. Short, B.Sc.,* H. H. Wills Physical Laboratory, University of Bristol

[*Note received* 8 *November*, 1956]

In attempting to grow crystals by vapour-phase sublimation, it is customary to use an electric furnace for producing a suitable temperature gradient. It is inevitable that with the normal type of electric furnace the progress of an experiment cannot be followed. The degree of success achieved cannot



Direct-vision crystal growth furnace

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* Now at the Research Laboratories of The General Electric Co. Ltd., Wembley, Middlesex.

be ascertained until after the completion of the experiment. A furnace (shown in the figure) was constructed therefore, in which the course of each experiment could be followed visually, and in which the effects of variations in the temperature and temperature gradient could be seen. It has been used successfully up to 600° C, and could doubtless be used at higher temperatures.

The visibility is achieved by using a liner of pure fused quartz, wound with relatively widely spaced Kanthal wire (by Aktiebolaget Kanthal, Hallspahammar, Sweden). A Pyrex plate let into the side of the furnace allows direct vision into the interior. To minimize radiant heat losses through this window, a slotted nickel foil reflector is placed between the liner and the plate.

The sublimation tube, in which the crystals are to be grown, is positioned in the centre of the furnace so that the platinum/rhodium-platinum thermocouple junctions just touch the surface of the tube. This is most important as it is desirable to know as accurately as possible the temperature distribution along the sublimation tube.

The furnace tube is wound with five separate coils of 19 s.w.g. Kanthal A.1 wire, approximately six turns per inch. The length of each coil is shown in the figure. The two end coils prevent too rapid a fall in temperature at the ends of the furnace tube, and the two adjacent coils provide the desired temperature gradient. It was found to be most important that the turns should be evenly spaced, otherwise hot and cold spots are formed along the tube. The current in each coil was controlled by a separate Variac transformer, *via* a high current transformer.

The Variac transformers were supplied by an automatic voltage stabilizer which maintained the input constant to within $\pm\frac{1}{2}$ V. The thermocouple outputs were recorded on a multi-channel potentiometric recorder [by Elliott Bros. (London) Ltd.]; the temperatures were stable to within 1° C.

The work described above has been carried out as part the general research programme of the National Physic Laboratory and this note is published by permission of Director of the Laboratory.

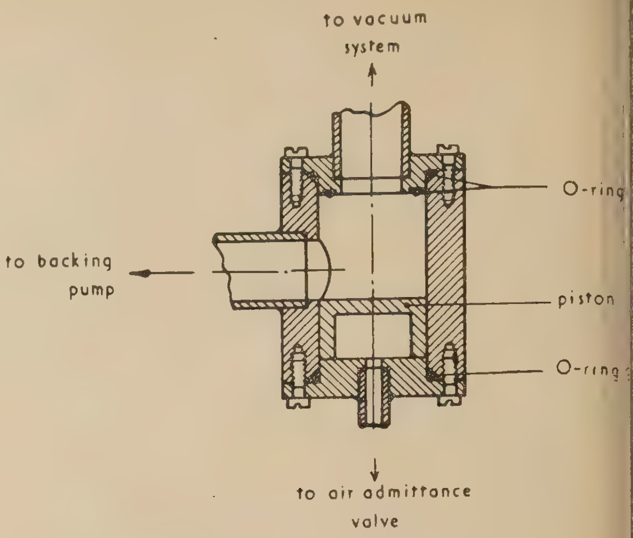
An automatic vacuum isolation valve

By A. Franks, Ph.D., A.Inst.P., National Physical Laboratory, Teddington, Middlesex

[*Note received* 4 *October*, 1956]

In the event of a failure of a rotary backing pump in a continuously evacuated system, it is desirable to admit air to the pump in order to prevent oil being forced into the backing line, and simultaneously, to maintain a vacuum in the remainder of the system to protect, for example, any heated components (e.g. diffusion pump, vacuum furnace).

A number of isolation valves of varying complexity have been described, usually relying on springs or electromagnets for their operation.* A simple gravity-operated isolation valve is shown in the figure.† It is used in conjunction with an air admittance valve (by Edwards High Vacuum Ltd.) which opens on failure of the mains supply. Alternatively, the air admittance valve may be actuated by a generator coupled to the pump. The piston is a good sliding fit, without shake, in the cylinder. When the air admittance valve opens, the piston is forced upwards against an O-ring and isolates the vacuum system from the atmosphere; at the same time air enters the backing pump. On starting the rotary pump, the space below the piston is partially evacuated so that the piston sinks downwards to its initial position.



Automatic vacuum isolation valve

A technique for hardening beryllium copper

By R. A. Cox, Ph.D., A.R.C.S., National Institute o Oceanography, Wormley, Surrey

[*Note received* 23 *October*, 1956]

Beryllium copper is a most useful alloy for instrument construction, particularly for parts requiring spring properti It can be supplied in the "annealed" condition, i.e. soluti treated, in which form it can be manipulated by standar engineering processes, and the finished parts can then hardened by a simple heat treatment. Such components coil and leaf springs, meter suspensions and flexible coupling can be made more readily in this alloy than in any othe material with equivalent properties.

Unfortunately the temperature necessary to harden th alloy (about 315° C) is beyond the range of most laborator ovens. Moreover it is desirable to protect the metal fro oxygen and sulphur compounds during the heating, as otherwise a surface film of scale is produced, and its removal ca cause serious loss in dimensions when very small and thi sections are involved. This is especially true in small spring where the spring rate depends on the cube of the thicknes It is, of course, possible to provide a furnace with a protectiv atmosphere, and this is the usual solution for a worksho where hardening is a routine operation. The expense of suc an apparatus could seldom be justified for the occasional us likely in a research laboratory.

Benzyl benzoate is an organic liquid boiling at 320° C. is reasonably cheap, is stable and not very offensive in sme It has been found that immersion in boiling benzyl benzoa is a simple and effective means of hardening beryllium coppe For small items a boiling tube quarter-filled with liquid an loosely corked is suitable. Heated by a small flame th benzoate refluxes gently on the walls of the tube. No condenser is necessary. For larger items a conical beaker, use in a similar way, is suitable. If necessary the parts to rdened may be clamped between plates or otherwise trained to avoid distortion. The figure shows the hardness icker's scale) of "annealed" samples after various times of atment. The author recommends boiling "annealed" items : 2–2½ h and half-hard metal (cold worked) for 1 h. It is

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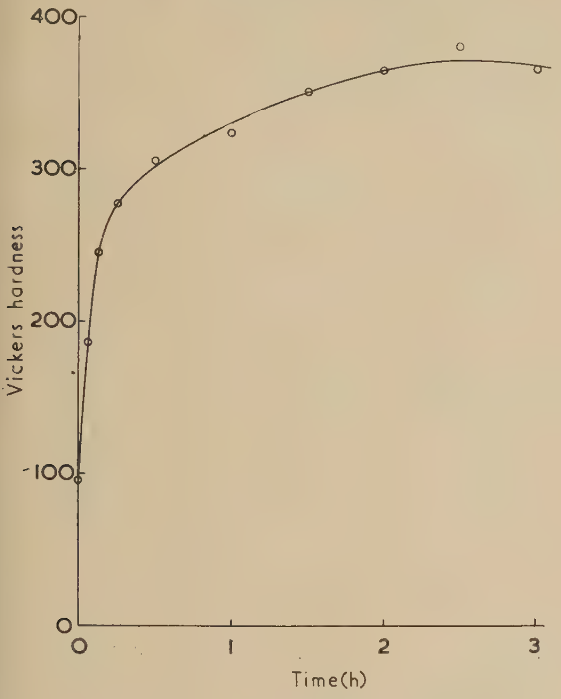
* Green, G. W. *J. Sci. Instrum.*, **26**, p. 206 (1949).
† British provisional patent 20058/56.



Variation of hardness of "annealed" specimens with time of treatment

sirable to use a fresh quantity of benzoate for each opera-on, as, unless it is distilled after use, the accumulation of idation products slowly lowers the boiling point. If the nzoate is allowed to cool before the alloy is removed there no detectable attack whatever on the metal.

Indium seals for dismountable vacuum systems

By the late H. A. Adam, A.M.I.E.E., Grad.Inst.P., S. Kaufman, B.Sc., Ph.D., Grad.Inst.P., and B. S. Liley, M.Sc., Associated Electrical Industries, Research Laboratory, Aldermaston, Berks

[*Note first received* 2 *May, and in final form* 12 *November,* 1956]

ı dismountable vacuum systems when the presence of hydro-rbon vapours is undesirable, seals employing metal gaskets e superior to seals with rubber or neoprene. Aluminium, pper, lead, silver and tin have been commonly used as skets.(1) In the present investigation, it was required to oduce a metal seal for applications where no external amping was possible and compression of the seal was due lely to atmospheric pressure. Indium was considered a ely material as it is very soft and has a negligible vapour essure at room temperature.

Preliminary measurements indicated that satisfactory cuum seals could be obtained with indium, sealing gaps tween faces of brass and polished Pyrex glass. The indium ire, diameter 1/16 in. (1·6 mm), was retained in a circular oove of trapeziform cross-section cut in the metal. The idth of the groove was 0·059 in. (1·50 mm), its greatest depth was 0·054 in. (1·37 mm) and its least depth 0·018 in. (0·46 mm). The tolerance on all dimensions was 0·001 in. (0·025 mm). The depth of the groove was so chosen to allow a small ridge of indium to form between the sealing surfaces. The thickness of the ridge after several days of pumping was about 0·010 in. (0.25 mm). The indium gasket was made by selecting a length of wire equal to the mean circumference of the groove minus a few millimetres. The ends were cut off square and butt-jointed in a small flame with the aid of suitable flux, e.g. Coraline soldering paste. Excess metal in the joint was pressed out in a jig and peeled off. The wire ring was then pressed into the groove after slight stretching to remove uneveness. Care was taken to ensure that the wire was neither indented nor unduly stretched. The minimum load required to form a seal was 5·9 kg wt/cm length of wire. It thus appeared possible to form vacuum seals on tubes of minimum diameter 23 cm utilizing atmospheric compression alone.

Seals of large diameter were formed between wedge-shaped rings of an aluminium alloy M27 (by the British Aluminium Co. Ltd.) and rings of porcelain. In this instance, the groove was rectangular and had a mean diameter of 33·1 cm. The cross-sectional area of the groove was the same as for the trapezium. Pre-squashing of the indium until it projected 0·030 in. (0·76 mm) above the surface of the alloy prevented any possible displacement of the indium before compression was applied and assisted the formation of a rough vacuum. Typical profiles of the different surfaces of porcelain tried are shown in Fig. 1. The results of measured leak rates are tabulated in the table. The apparent leak rate of the vacuum system without the test apparatus, as measured with either a Pirani or an ionization gauge, varied between $1 \cdot 5 \times 10^{-3}$ and 2×10^{-3} μl sec^{-1}. The components of the test apparatus were cleaned in a vapour bath of acetone, except in the experiments with a surface of type *B* (*i*). In this instance, the cleaning was not thorough. A vacuum seal could not

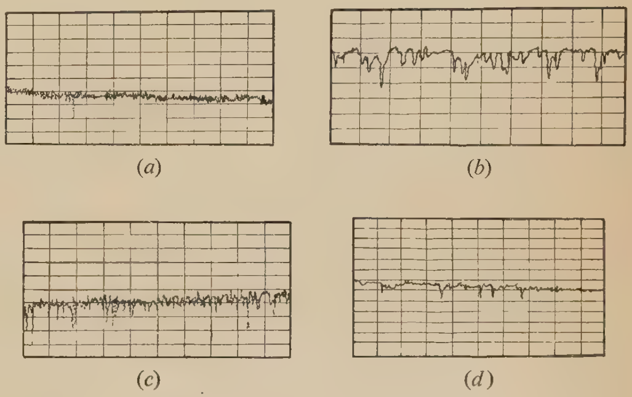


Fig. 1. Surface profiles of porcelain rings and glass (for comparison)

(*a*) Plate glass:	vertical magnification	× 50 000
	horizontal magnification	× 30
(*b*) Ground porcelain:	vertical magnification	× 1000
	horizontal magnification	× 25
(*c*) Lapped porcelain:	vertical magnification	× 2000
	horizontal magnification	× 30
(*d*) Polished porcelain:	vertical magnification	× 2000
	horizontal magnification	× 30

Scale: For (*a*), (*b*), (*c*) each vertical division is 0·1 in. (0·25 cm) and each horizontal division 0·2 in. (0·51 cm). For (*d*) each vertical division is 0·2 cm, and each horizontal division 0·5 cm.

be formed either for a surface of type *B* (*ii*) or *C*. The result for *B* (*ii*), for example, was typical of six trials. The combined evidence of the measured leak rates and surface profiles is conclusive proof that with an atmospheric load of 8·6 kg wt/cm of wire, a very clean surface of porcelain must be highly polished before a vacuum seal can be obtained. A vacuum seal can be formed on a ground porcelain which has not been properly cleaned because grease or dirt seals the crevices in the porcelain surface.

Apparent leak rates for different surfaces of porcelain and glass (*for comparison*)

Surface	$10^3\,Q$ ($\mu l\ sec^{-1}$)
A	1·5
B (*i*)	2·0
(*ii*)	1000
C	140
D	1·5

A, plate glass [Fig. 2(*a*)].
B, ground porcelain [Fig. 2(*b*)].
C, lapped porcelain [Fig. 2(*c*)].
D, polished porcelain [Fig. 2(*d*)].
Q, leak rate.

The test apparatus could be opened to the atmosphere and evacuated again without any change in the leak rate, provided there was no movement of the indium relative to the ring. Vacuum seals were also easily obtained with different combinations of sealing surfaces, such as steel–steel, steel–porcelain and steel–alloy M27. Mention may be made of an application of the seals. A standard type of vacuum union (Fig. 2) can be readily modified for use with an indium gasket instead of a rubber washer. The seal is made by screwing together the two sealing faces.

A hypothesis has been advanced to relate the sealing mechanism to the hardness properties of indium. The Meyer hardness of indium is not independent of the size of the indentor, the hardness being greater the smaller the diameter of the indentor.(2) Similarly, when the sealing surface consists of irregularities of small "diameter" [see Fig. 1(*b*)], the load required to form a seal is greater than in the case when the sealing surface is very smooth, i.e. virtually of infinite diameter [see Fig. 1(*d*)]. This would explain why a seal cannot be obtained with a ground porcelain, but can be with a polished one. It is also suggested that seals for high temperature may be obtained with the minimum of loading by using a metal with the appropriate properties of hardness and creep at the operating temperature. Substantial bolting of the sealing flanges would then not be necessary.

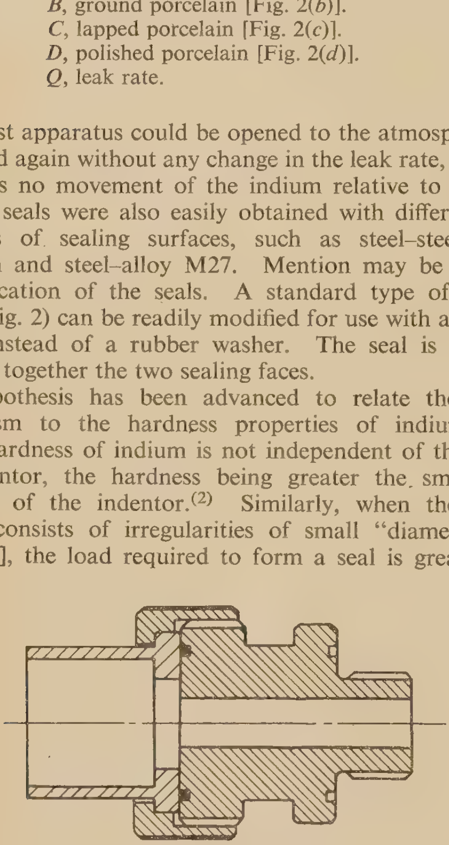


Fig. 2. Vacuum union for ⅝ in. diameter tubing. Scale: full size

We thank the members of the laboratory who contributed to the experimental work, in particular Mr. R. N. Bloomer Dr. A. W. Crook and Mr. B. A. Shotter. We are indebte to the Director of the Laboratory, Dr. T. E. Allibone, fo permission to publish this note.

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(2) Rubenstein, C. *Proc. Phys. Soc.* [*London*] *B*, **67**, p. 56 (1954).

A sealing compound for glass-to-metal joints of optical instruments

By K. Hillman, B.Sc., A.R.I.C., Chemical Inspectorate,
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[*Note received* 20 *November*, 1956]

Certain proprietary sealing compounds have given unsatisfactory results when used in optical instruments for sealin glass-to-metal, especially under tropical conditions. Formulations made up in the laboratory and based on bitumen rubber and ceresin wax in various proportions have likewi not satisfied all requirements in respect of ease of applicatio low temperature stability, consistency at tropical temperatur resistance to weathering and, in particular, adhesion to gl and metal surfaces.

Experiment has shown that a marked improvement plasticity and adhesion can be effected if a blend of t microcrystalline waxes is substituted for the ceresin wax the above compositions. One of these waxes should chosen with a view to imparting plasticity to the compositio the other wax should be a high melting-point wax chosen prevent undue softening at tropical temperatures. Th relative proportions of the two waxes can be adjusted that the final product retains the necessary degree of plasticit over the required temperature range. Compositions base on this principle have been made, and have been found to b eminently satisfactory.

A range of different microcrystalline waxes is available, and from the published characteristics of these waxes it should be possible to choose a pair which, when blended in suitabl proportions, will satisfy the requirements given above. On formulation is mentioned below by way of example, but the microcrystalline waxes specified therein are only two selecte from a wide range of materials, many of which might wel provide products of satisfactory sealing properties.

Example of new formulation

Wax Plaso 2*	3 parts by weight
Okerim Wax 604†	11 parts by weight
Pale crepe rubber	3 parts by weight
Bitumen 80/90	4 parts by weight

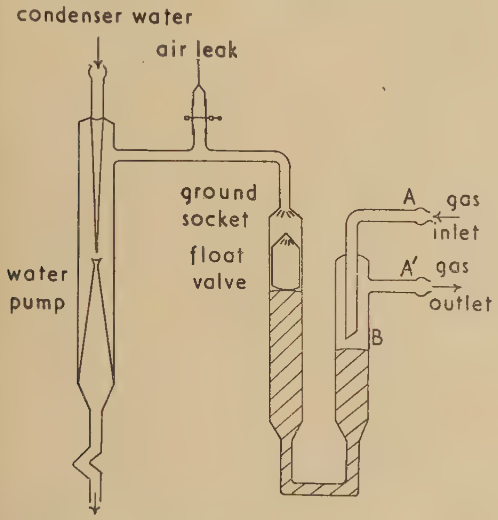
* Manufactured by Claud Campbell and Co.
† Manufactured by Aster Boisselier and Lawrence Co.

The method of blending was as follows. The two waxes (fourteen parts) were melted together, and the crepe rubber (three parts) was milled for five minutes in a 12 in. open-type laboratory rubber mill. Part of the wax mixture (nine parts) was then added to the crepe rubber and milled-in for ten minutes, at the end of which time the temperature had risen to 60° C. The product was then incorporated with the remaining wax mixture (five parts) and the bitumen (four parts) by mixing at 130° C for twenty minutes.

Correspondence

Water failure guard for use with gas-heated pumps

veral methods of guarding against condenser water failure diffusion pumps have appeared in this *Journal*.* These ply, however, only when the pump is electrically heated. have therefore designed the following safeguard for use h gas-heated pumps.



The outlet water from the condenser (see the figure) passes rough a water pump. The resulting pumping action is fficient to raise a column of mercury which in turn allows e passage of gas through *AA′*. If the water should fail, mercury falls back, cutting off the gas.

In operation the following points may be noted.

(1) To prevent irregularities of pressure and consequent "hunting" of the mercury, the water pump exit should be as illustrated.

(2) The ground glass valve prevents mercury from being sucked into the pump during setting of the apparatus.

(3) The efficiency of the pump can be altered by means of the air leak. The apparatus can then be used at any desired rate of water flow with the cut-off operating at any pre-determined minimum rate.

(4) As the mercury rises, shutting off the gas flow, there may be a short period during which there is some bubbling. To guard against any danger from this, and the possibility that the water may be turned on again, we suggest a pilot light be used.

(5) "Edging" the tubing at *B* reduces bubbling considerably.

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R. F. Smith
B. Sunners

(18 October, 1956)

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* Houghton, G. *J. Sci. Instrum.*, **33**, p. 199 (1956).
Croft, A. J. *J. Sci. Instrum.*, **25**, p. 386 (1948).

A method for comparing ultrasonic velocities in solids and liquids using a spectrometer

eekantath and Mathai in a note published on p. 361 of e September 1956 issue of this *Journal* show that, in the Debye–Sears' method, the diffraction pattern is clear and visible only when the light wave-front is normal to the sound beam. But it is known that at higher frequencies (which are of most interest) the maximum of intensity of the last visible line can only be observed by realizing Bragg's equation. At other angles the diffraction pattern is not always visible.(1) On either side of the Bragg maximum there are periodical further maxima of decreasing intensity. Investigations on the dependency of intensity with angle are given by Nomoto and others.(2–6) Measuring by this arrangement may be possible by taking into account this effect. But the experiments of Korff(7) point to a shifting of zero in relation to both possible corrections of the Bragg angle. This may be only explained by the existence of inclined light or of a sound beam of large intensity. It is known that a quartz transducer has the characteristic of a piston source, but the sound field is not homogeneous everywhere, for there is also an interference field.

Two conditions must be fulfilled for using the method described. First, production of a homogeneous sound field, and second, production of an exactly parallel light beam. The control of the field would be very troublesome and would not be possible without changing the arrangement. This control has to be repeated for every medium. Furthermore, subjective observation is not to be recommended. Unfortunately the note does not say clearly what is to be understood by "ordinary diffraction method." If the authors mean the measurement of the velocity from the separation of diffraction lines, it is true that these distances may be measured very accurately by a photographic method with a lens of large focal length.

It seems that the methods of Bär, Schaefer and Willard(8–11) are more accurate than this arrangement. The sound field there is controlled directly. The evaluation then follows by means of a photographic plate, taking into consideration the possible error.

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E. Hayess

(22 November, 1956)

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The methods of Bär, Schaefer and Willard may be more accurate, but the method we found satisfactory is applicable to quick routine investigations. Reflexion at the Bragg angle, accompanied by enhancement of intensity of some of the higher orders and the appearance of non-symmetry in the diffraction pattern, may be avoided by keeping the intensity of the sound field low by controlling the amplitude of vibrations of the quartz transducer, as in our method. Under these conditions the intensity of the higher orders of the diffraction spectra at normal incidence will be progressively weak compared with that of the central order and the slightest non-alinement from normal incidence will make the higher feeble orders on either side of the central order vanish, making it possible to set the sound beam accurately normal to the light beam.

Certainly the conditions (1) the production of a parallel beam of sound and (2) the production of a parallel beam of light have to be satisfied. But the percentage error due to want of absolute fulfilment of these conditions is reduced by using a solid prism of large angle. The simplicity of the method lies in the minimum equipment needed, doing away with an elaborate photographic technique; the subjective observation adopted is found quite reliable in actual practice.

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G. M. Sreekantath
and
A. O. Mathai

(17 December, 1956)

A trigonometric analogous computer using linear elements

This note explains the basic theory of a simple trigonometric computer using linear elements. The computer gives the natural trigonometric functions of the angle ϕ varying between 0 and 90°. The scheme is so simple that it is possible to demonstrate its applications in a very short time.

Table 1. *Relation between ϕ, r and c*

ϕ (deg)	0	10	20	30	40	50	60	70	80	90
$r = \cot\phi/2\pi fc$ (Ω)	∞	5·67	2·75	1·73	1·19	0·84	0·58	0·36	0·17	0 × $1/2\pi fc$

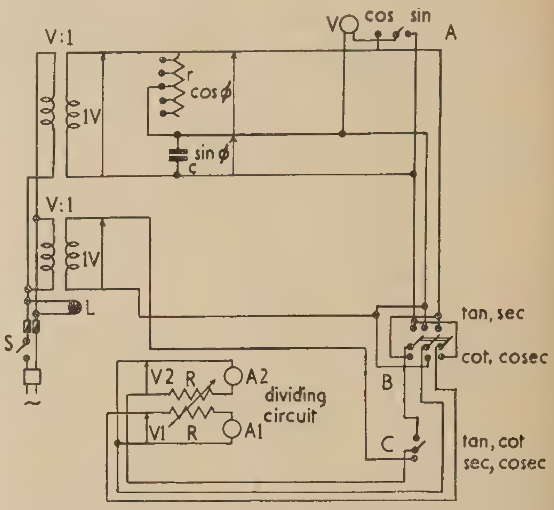
The basic circuit diagram is shown in the figure. One volt (a.c., r.m.s. value) is applied to the resistance-capacitance circuit such that the voltages appearing at the terminals of the resistor r and the capacitor c, with the frequency of the supply f (where r is measured in ohms, c in farads and f in cycles/s), will be respectively $\cos\phi$ and $\sin\phi$ where $\tan\phi = 1/2\pi frc$. It follows that, making use of switch A, the voltmeter V having a maximum range of one volt will read the cosine or sine function.

Values of r and c relative to ϕ may be fixed using the values given in Table 1 if c is assumed constant.

Hence the resistor r may be made of wire, wound and calibrated to give the given values for the corresponding angles.

It can be shown that, with reference to the dividing circuit given in the figure, if voltages of magnitudes of $V1$ and $V2$ are applied respectively to the lower and upper circuit, and if the two identical mechanically coupled resistances (RR) are adjusted such that 1 mA flows through the current meter $A1$ of the lower circuit, then the value in milliamperes read on the current meter $A2$ of the upper circuit will be the scaler value of $V2/V1$.

Thus making use of the switches B and C, certain voltages may be applied at $V1$ and $V2$ terminals such that, afte adjusting the resistors (RR) in each case to let 1 mA flow through $A1$, the remaining natural trigonometric functio of the angle ϕ may be obtained, in accordance with Table 2 as milliamperes on the current meter $A2$.



Basic circuit diagram of a simple trigonometric analogous computer

S, switch followed by fuses; *L*, on/off lamp.

It follows that the cosine and sine functions are obtain by using switch A, while the remaining natural trigonomet functions are found by using switches B and C in accordan with Table 2.

Test results might have been given but they vary from on type of equipment to another and the results obtained fo one type of equipment do not necessarily apply for anothe type. Moreover, the inaccuracy of this type of circuit i well known. The accuracy of the circuit depends on: th values and degrees of perfection of the elements used, th method of their loading and the supply freedom from har monics and non-constancy.

Table 2. *Switch positions, values of $V1$ and $V2$ and curren meter readings*

Position of switch B	switch C	*Value of* V1 (volts)	V2	*Reading of* A1 (mA)	A2 = V2/V1
tan, sec	tan, cot	$\cos\phi$	$\sin\phi$	1	$\tan\phi$
cot, cosec	tan, cot	$-\sin\phi$	$-\cos\phi$	1	$\cot\phi$
tan, sec	sec, cosec	$\cos\phi$	-1	1	$\sec\phi$
cot, cosec	sec, cosec	$-\sin\phi$	-1	1	$\mathrm{cosec}\,\phi$

It should be remembered, during experimental work that the computer is a one-frequency instrument; th frequency being used in calibrating the resistance r i Table 1.

The important aspect of developing such a computer is i designing a complete trigonometric machine, using linea ents, to solve trigonometric equations; this is being stigated.

valuable use for this computer would be a servo- ianism system to position the potentiometer auto- cally. Within the limits of the speed response on the omechanism, this would make the circuit applicable to various kinds of analogue computers employing such trigonometric equations in their operation or representation.

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M. S. M. Abou-Hussein
(2 January, 1956)

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

enses and condensers. Hilger and Watts Ltd., 98 St. cras Way, Camden Road, London, N.W.1. Leaflet 433) gives details of two new lenses, ×200 and ×500, ch are now available for use with production projectors. ails are also given of a new condenser for use with lenses 50 or ×100 magnification.

-ray microphotometer. Hilger and Watts Ltd., 98 St. cras Way, Camden Road, London, N.W.1. A 4-page er (CH294/5) gives details of the modified versions of the ger microphotometer which have been designed for suring the intensities and spacings of diffraction lines on tographic film. Two versions are described which are hand-driven non-recording microphotometer (L481) and motor-driven recording microphotometer (L486).

igh-intensity surface illuminators. Hilger and Watts Ltd., St. Pancras Way, Camden Road, London, N.W.1. flet (CT 422) announces new high-intensity illuminators projectors TT476 and TT750 which the manufacturers m will give efficient results with test objects for which eral-purpose illuminators often prove unsatisfactory.

lectronic and other instruments and components. Gulton ustries Inc., 212 Durham Avenue, Metuchen, New Jersey, .A. An illustrated brochure briefly describes the wide ge of scientific instruments and electrical devices made by firm and its associates.

yepiece and stage graticules. James Swift and Son, Ltd., -115a Camberwell Road, London, S.E.5. An illustrated age leaflet describes a comprehensive range of eyepiece stage graticules for use with microscopes and other optical ruments.

lectronic instrument apparatus. E.M.I. Electronics Ltd., yes, Middlesex. In connexion with a special electronics ibition recently held in London by this firm a number of lets have been issued concerning oscilloscopes, a digital ay generator, an amplifier, a microwave wattmeter, hode followers, an X-band klystron cavity, a stroboscope, ultistrobe and other electronic equipment.

lectromagnetic pilot valves. Baldwin Instrument Co. Ltd., rtford, Kent. A new 8-page section of the firm's umatics catalogue has just been issued, dealing with tromagnetic pilot valves.

ecade resistance units. Muirhead and Co. Ltd., Becken- n, Kent. Leaflet 1742-A gives particulars of improved n-reactive decade resistance units.

rogramme temperature controller. Ether Ltd., Tyburn ad, Erdington, Birmingham, 24. A press release announces new self-contained direct deflexion instrument which icates and controls temperature to close accuracy over a le range in strict accordance with a predetermined time gramme.

Galvanometer. Evans Electroselenium Ltd., Harlow, Essex. Leaflet No. L. 130 describes a new high sensitive galvanometer for which several unique advantages are claimed.

Electronic measurement equipment. Marconi Instruments Ltd., St. Albans, Herts. An impressive 276-page illustrated catalogue describes the range of telecommunication measurement equipment and industrial electronic instruments manufactured by this firm. The catalogue is divided into 11 sections under the following headings: Signal sources; Frequency meters; Voltmeters; Power meters; Distortion meters; Field strength meters; Transmission monitors; Deviation meters; Oscilloscopes; Spectrum and response analysers; Standing-wave meters; Q meters and bridges; Industrial equipment.

Null-balance potentiometer. Integra, Leeds and Northrup Ltd., 183 Broad Street, Birmingham, 15. An eight-page illustrated pamphlet describes the new Speedomax Type H null-balance potentiometer. This instrument is available at present for temperature measurement only.

Measuring instruments and tools. Eric H. Bernfeld Ltd., 282 Kingsland Road, London, E.8. A price list of measuring instruments and tools made by continental manufacturers has been made available by this firm.

Reed vibrometer. Salford Electrical Instruments Ltd., Peel Works, Silk Street, Salford 3, Lancs. A folder describing a reed vibrometer to be used for the determination of mechanical linear vibrations has been made available by this firm.

Beam switch. Furzehill Laboratories Ltd., Watford, Herts. Leaflet S.1 describes the Furzehill Type S. 500 beam switch for use with an oscilloscope. This instrument permits two separate inputs to be displayed, in their correct phase and amplitude relationship, on a single beam tube.

Gas liquefier. North American Philips Co., Inc., Instruments Division, 750 South Fulton Avenue, Mt. Vernon, N.Y., U.S.A. A six-page folder describes the Norelco gas liquefier which the manufacturers claim to be unique in that the gas to be liquefied does not pass through the working parts, but merely condenses on the surface of the cylinder head.

High vacuum rotary piston pumps. N.G.N. Electrical Ltd., Cawdor Street, Patricroft, Manchester. Leaflet No. 881/16 describes the new range of gas ballast high vacuum rotary system pumps which are manufactured by this firm.

Valves. Mullard Ltd., Mullard House, Torrington Place, London, W.C.1. The new edition of the Mullard pocket data book has just been issued which includes details of entertainment valves, cathode-ray tubes and germanium devices introduced since the previous edition in 1954. An improved format has been devised which presents the data in a simplified form.

Notes and comments

The Physical Society's annual exhibition of scientific instruments and apparatus

The Physical Society announces that its forty-first annual exhibition will be held at the Royal Horticultural Society's Old and New Halls, Westminster, London, S.W.1, from 25–28 March, 1957 (inclusive).

Entrance to the exhibition is by ticket only and these may be obtained, free of charge, from the offices of the Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7. Members of The Institute of Physics may obtain tickets from the Institute's office. The handbook of scientific instruments and apparatus published in connexion with the exhibition is available from the Society, price 6*s.*; by post 7*s.* 6*d.*

World directory of crystallographers

The International Union of Crystallography is considering the possibility of preparing a World directory of crystallographers. This list would contain the names and addresses of all practising crystallographers, including advanced graduate students. It is planned to compile a preliminary list in time for the Fourth General Assembly to be held in Montreal, 10–17 July, 1957. The secretaries of the national committees (*Acta Cryst.*, **8**, p. 857, 1955) have been asked to prepare a list of crystallographers in their countries. Some scientists and technologists, however, who carry on crystallographic work (including X-ray, electron or neutron diffraction and microscopy or other techniques) are not members of scientific societies having a unique crystallographic interest, and might therefore be missed. Those who come into this category are asked to send their names and addresses, in printed letters, to Dr. William Parrish, Philips Laboratories, Irvington-on-Hudson, New York, U.S.A.

Data processing section for the Radio Communication and Electronic Engineering Association

The Council of the Radio Communication and Electronic Engineering Association has approved the formation of a section to deal with electronic data processing, to be known as the Data Processing Section.

The decision followed the recommendations of a meeting of representatives of ten member-firms of the Association. Chairman of the section is Mr. C. Metcalfe, managing director of E.M.I. Electronics Ltd., and a data processing technical sub-committee has been formed. The new section is intended to serve the interests of the many firms who are concerned in the new field of electronic computer equipment, both digital and analogue, and also the manufacturers of input and output devices and allied equipment. Broadly, the scope of the section will be: Electronic computers (digital and analogue), Electronic data handling equipment, Electronic data reduction equipment, Electronic automatic control systems, Electronic plotting equipment, Electronic digital telemetering systems, Electronic test equipment for digital or analogue computers.

It is believed that the work of the section will be of inter
to a number of manufacturers not at present members of t
Association and applications for membership of the d
processing section only are being invited. Sections of t
Association previously formed deal with aviation, mari
uses, mobile radio and industrial electronics.

New isotope catalogue

A fourth edition has been published of the catalogue
isotopes on sale from the Isotope Division, Atomic Ener
Research Establishment, Harwell. The principal section
the catalogue consists of a table giving the properties a
availability of individual pile-produced radioisotopes. Bo
this section and the one on cyclotron-produced and stab
isotopes have been expanded, to cover those materials whi
have become available since the previous editions of t
catalogue.

The remainder of the catalogue includes a description
the specialised services which the Isotope Division is able
provide on request; information on general topics such
the control of health hazards and on the preparation
radio-isotopes; details of facilities offered by the Technologi
Irradiation Group for high-intensity ionizing irradiation
materials; information on radioactive standards prepared
Harwell; and tables of beta and gamma energies aga
half-lives.

There is a comprehensive index to the contents of t
catalogue so that it can be readily used for reference.

Copies of the catalogue may be obtained from the Isoto
Division, A.E.R.E., Harwell, Didcot, Berkshire. A separ
catalogue covering naturally radioactive materials, long-l
fission products, labelled compounds and other materi
requiring processing or synthesis is obtainable from t
Radiochemical Centre, Amersham, Buckinghamshire.

British Journal of Applied Physics

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New books

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CONFERENCE REPORT

Summarized proceedings of a conference on contemporary optics Sydney, 1956

A conference on contemporary optics was held by the Australian Branch of The Institute of Physics in Sydney on 19, 20 and 21 September, 1956. The conference was opened by Dr. F. W. G. White, President of the Australian Branch, who pointed out that the conference served to demonstrate the strength of optical research in Australia, where there have been major post-war developments in interferometry and in geometrical, physical and instrumental optics. The papers presented are summarized in this report.

GEOMETRICAL OPTICS

e first paper, by Mr. N. J. Rumsey (Dominion Physical boratory, New Zealand), on "Differential correction of ve-front aberration," dealt with a technique (developed lependently by Rumsey and by H. H. Hopkins of the perial College of Science and Technology) for completing ; design of an optical system when a rough design has been ablished by primary aberration theory or other means.

A number of selected rays are traced through the optical tem in the usual manner, and the wave-front aberration ng each ray determined from formulae such as those given Hopkins.(1) Simple formulae, making use of quantities ich appear in the ray-trace, then give the first derivative the wave-front aberration with respect to changes in the nstructional parameters—the curvatures (*c*) of the surfaces, separations (t') between successive surfaces, and the ractive indices (*N*) of the media. (Conrady's well-known –*D*" method is satisfactory for dealing with changes of ractive index and fits in logically with the new method.) ch differential coefficient has two terms. The first may be nsidered to arise naturally at the place where a construcnal change is made, but it gives the change in wave-front erration measured from the original reference sphere of pencil in question. The second term gives the change in aberration arising from change of the reference sphere to e centred on the new position of the image point. For s purpose the position of the image point may be chosen any one of several different ways; e.g. one may use the ussian (ideal) image point or, for oblique pencils, the int of intersection of the principal ray with the ideal image ne. Suitable methods for determining the new positions ve been described, e.g. by Cruickshank.(2) A more ractive method, however, is to choose the new position so to minimize the new wave-front aberration, for only antities already calculated are then required. When the ferential coefficients have been evaluated, they are used the numerical coefficients in simultaneous linear algebraic uations, where the constant terms are the desired changes wave-front aberration, and the unknowns are the changes ich must be made in the constructional parameters to hieve these aberration changes.

The method has much in common with Cruickshank's,(2) t has two noteworthy advantages. First, for high quality tems wave-front aberration gives a more direct indication image quality than transverse or longitudinal measures. cond, in Cruickshank's method it is necessary to calculate ansfer coefficients" to determine the effect in the image ice of changes within the system, whereas here changes be transferred to the image space without modification. the other hand, it does not appear possible to make use of the sine theorem with the new method, so it is sometimes advantageous to use both methods simultaneously.

The systematic design of photographic objectives was described by Dr. F. D. Cruickshank (University of Tasmania). As the optical literature does not afford much direct help in the problem of the synthesis and final correction of a modern photographic objective, a study is being made in the University of Tasmania of methods for the systematic design of objectives of the triplet family, having specially in mind those with compound members such as the Tessar, the Heliar or Pentac, the Hektor, etc. Corresponding to any thin doublet there is an equivalent thin lens of the same power which makes the same contribution to the Petzval sum and the chromatic aberrations as the doublet. This equivalent lens will in general have fictitious glass constants. Any triplet with compound members may therefore be reduced to an equivalent system of three separated thin lenses. Conversely, the first stage in the synthesis of a triplet with compound members is to arrive at an initial system of three thin equivalent lenses in which the desired paraxial properties of the final objective are achieved, together with the chosen values of the Petzval sum and the chromatic aberrations.

The first requirement, then, is a simple analysis of the system of three separated thin lenses (ϕ_a, N_a, V_a), (ϕ_b, N_b, V_b), (ϕ_c, N_c, V_c) between which are the airspaces t_1, t_2, where ϕ, N and V denote respectively the power of the lens, the refractive index of the glass and its reciprocal dispersion or V-value. It is convenient to regard the first two lenses as constituting a corrector system to the positive rear component of the system, as suggested in another paper.(3) Five conditions are now prescribed to be satisfied by the system: (i) the objective shall have unit power; (ii) the corrector shall have power χ; (iii) the Petzval sum shall be R_4; while, for an object plane at infinity and a diaphragm coincident with the second lens, the system shall have (iv) axial chromatic aberration R_6 and (v) transverse chromatic aberration R_7. The five equations expressing these conditions may be solved easily to give ϕ_a, ϕ_b, ϕ_c, t_1, t_2 as functions of the corrector power χ, the glass constants α, β, ξ, γ, where

$$\alpha = V_a/V_b, \quad \xi = V_a/V_c, \quad \beta = N_a/N_b, \quad \gamma = N_a/N_c,$$

and the residual aberrations P, L, T, where

$$P = R_4 N_a, \quad L = R_6 V_a/y_{0a}, \quad T = R_7 V_a/u_a$$

If we select a set of glasses and choose appropriate values for P, L, T, the powers and separations become simply functions of χ. A study of the equations then shows that useful values of χ lie generally within the range $-2 < \chi < 0$.

Variation of χ changes ϕ_b comparatively slowly, but results in considerable interchange of power between the positive lenses a and c. Thus χ takes on the significance that it is the variable which determines the distribution of the total positive power between the two positive components. There are four additional degrees of freedom within the thin lens system at this stage, namely, the "shapes" of the components and the value of χ. Relatively simple equations connect the shapes, S_a, S_b, S_c of the components with the primary astigmatism, distortion, and coma. These equations may be solved systematically to determine the shapes for any selected values of these primary aberrations. Finally, it is found that the primary spherical aberration is adequately represented as a quadratic function of χ in the range of χ-values which are of interest. This quadratic relation may provide two, one, or no solutions for the small assigned value of primary spherical aberration, according to the values of the coefficients in the relation. With appropriate choice of glass, then, there are at most two solutions corresponding to quite different values of χ providing thin lens systems corrected for all primary aberrations.

The assignment of finite thicknesses to the lenses introduces changes in the primary aberrations which can be compensated systematically by small changes in the shapes and χ. During this stage of the design opportunity is taken to set the diaphragm in a practical position in one of the air-spaces.

The replacement of a component of the triplet by a doublet may be regarded at first as simply providing a means whereby the restrictions imposed by the limited number of glass types available may be removed. On this basis we may treat the constants α, β, γ, ξ as continuously variable within a certain range, knowing that in general it is possible to achieve desired values of these constants by means of compound components. Since these glass constants enter into the equations specifying the five initial conditions it is possible to examine the effect of glass selection on the powers and separations of the thin lens arrangement of the system. Investigation shows that a general reduction of the powers of the components follows the increase of the constant β. For a given value of β the dependence of the powers and separations on α can be exhibited in a characteristic series of curves from which it is easy to select a favourable value of α providing reduced powers and desirable separations. If β is raised considerably it is necessary to increase ξ also to maintain reasonable separations between components. If it is sought to reduce the Petzval sum of the system a general increase in the powers of the components of the system follows. It is therefore possible to offset this by increase of β. Hence manipulation of the Petzval sum is possible over a considerable range simply by controlled glass selection.

In all these investigations aberration coefficients of third and fifth order are computed as a matter of routine using the valuable methods developed by Buchdahl.(4) By this means it is possible not only to balance the third order against the higher order aberrations, but as the computation gives the partial aberration coefficients at each surface of the system it is easy to see how a particular construction achieves its characteristic properties. The analysis of the fifth order aberration coefficients into partial coefficients at each surface provides also a basis on which to assess the possibilities of increased aperture or field inherent in a system and thus affords a useful means of making comparisons between alternative designs which may have similar general characteristics in the final image.

This higher-order aberration theory was reviewed by Dr. H. A. Buchdahl (University of Tasmania) in a paper entitled "Aberration coefficients and quasi-invariance."(4) He pointe out that the variables specifying a ray traversing a sym metrical optical system may be so chosen that in the paraxi limit the relations between these variables at differen refracting surfaces are linear. The non-linearity of th corresponding relations for a finite ray is a measure of th imperfection of the system. Again, one may define a "quas invariant" Λ which reduces to the usual paraxial Lagrang invariant λ in the paraxial limit, and the difference betwee the final and initial values of Λ is a measure of the defec of imagery inherent in the system. By operating solely wit quasi-invariants and quasi-linear variables it is possible t devise a process of iteration whose first, second, third, . . steps yield respectively the primary, secondary, tertiary, . . monochromatic aberration coefficients, the latter bein essentially the coefficients of the series for Λ (in the imag space) in ascending powers of suitably chosen quasi-linea variables. The refracting surfaces need not be spherical. computing scheme for the whole set of primary and secondar coefficients, for instance, requires only fifty-four entries pe surface.

The iterative method may be extended to the calculatio of exact chromatic aberration coefficients of all kinds.

The idea of the "equivalent variation" combined with th process of iteration makes it possible to calculate the exac first and higher derivatives of the monochromatic an chromatic aberration coefficients of the various kinds wit respect to the separations, axial curvatures, extra-axia curvatures, refractive indices and dispersions specifying th constitution of the system. This allows of the calculation o the effect of finite changes in the constitution of the syste introduced for the purpose of improving its performance.

In a further paper, Dr. Buchdahl drew attention to particularly simple form of the dispersion equation. An analytical description of the chromatic behaviour of optica systems implies the specification of a number of aberratio coefficients as functions of the wavelength λ of the light used If G is such a coefficient, one might be inclined to write

$$G(\lambda) = G(\lambda_0) + g_1(\delta\lambda) + g_2(\delta\lambda)^2 + \ldots$$

where $\delta\lambda = \lambda - \lambda_0$, λ_0 being an arbitrary base wavelengt chosen to suit, and the g_i are constants. The dependence o the aberration coefficients G on λ arises from their dependenc on the refractive indices of the glasses used, and these i turn depend on λ. But refractive indices expressed in power of $\delta\lambda$ do not give a rapidly convergent series and hence th above series is of no use in practice. However, a rapidl convergent series can be found in powers of the parameter

$$\omega = \delta\lambda/[(1 + 5\delta\lambda/2)]$$

In the visible spectrum, two terms of the series are generall sufficient(4) for all glasses, and even for transparent crystals.

Dr. W. H. Steel (Commonwealth Scientific and Industria Research Organization, Division of Physics, Sydney) spok on developments in reflecting microscope design. He con sidered the problem of designing an objective using reflectin surfaces only, so that it could be used outside the visibl spectrum without changing from the visible focus. Surface were restricted to spheres; a design involving aspheri surfaces has been given by Burch.(5)

In earlier work(6) it was shown that two spherical mirror could only be corrected simultaneously for spherical aber ration and coma for a value of the central obscuration of th pupil higher than desirable for good image contrast. Th obscuration could be reduced by using three mirrors, and i suggested that with four mirrors the numerical aperture l also be increased above the value of 0·5 which is the for two or three mirror systems.

ie primary and secondary aberration characteristics of oinations of two sets of mirror pairs have now been ed. To keep the field investigated within useful obscura- , the value of the obscuration has been used as a para- r in specifying the aberrations. Contrary to earlier ations, it has been shown impossible to correct the ndary spherical aberration completely, or to increase numerical aperture appreciably. Some low obscuration ms have been designed, however, as they seemed pre- ble to three mirror systems, yielding "straight through" s of objective. The vignetting problems of these objectives discussed.

o reach higher apertures it seems necessary either to make pair of mirrors as a "solid" component and use the cting surface introduced as a further variable to correct ystem, or to remove the residual aberration by aspherizing or more surfaces. Such aspherizing would be much less that required for the Burch objective.

r. F. A. Dixon and Dr. J. V. Ramsay (Weapons Research blishment, Adelaide) reported on lenses covering fields ter than 180° without correcting distortion and on the of aspheric surfaces in long focus catadioptric objectives ectively.

RADIATIVE TRANSFER

r. R. G. Giovanelli (Commonwealth Scientific and istrial Research Organization, Division of Physics, ey) outlined methods developed by J. T. Jefferies and elf for the solution of multi-dimensional radiative sfer problems, such as arise when bounded diffusing ia are irradiated non-uniformly, or contain non-uniformly ibuted sources, or when the media themselves possess uniform properties.

sing an approximation similar to that introduced by ington, the equation of radiative transfer becomes

$$\nabla^2 J = 3\kappa^2(\lambda J - 4\pi S)$$

e κ is the attenuation coefficient, $1-\lambda$ is the albedo for e scattering, J the total intensity of radiation at a point, S the source function. The exact details of the method for the solution of this equation depend on the boundary litions and mode of irradiation for the problem, but they ely on either or both the following: (*a*) possibility of nding J in a series of harmonics appropriate to the netry; or (*b*) the juxtaposition of two media of more plex shape to form a medium of simpler shape whose erties are known.

or example, (*a*) can be used to examine the case of a -infinite diffuser irradiated non-uniformly by diffuse $F_0(x)$ whose intensity varies only in the x dimension ss the surface: then $F_0(x)$ may be resolved into

$$F_0(x) = \Sigma\alpha_n \cos nu, \quad n = 0, 2\pi k, 4\pi k, \ldots$$
$$u = \kappa x\sqrt{3\lambda}$$

ie simplest case where λ is small the source function may eglected, provided appropriate boundary conditions are , whence the solution is found

$$J = \Sigma \frac{\alpha_n \exp\left[w\sqrt{(1+n^2)}\right]}{1 + 2\sqrt{(\lambda/3)(1+n^2)}} \cos nu, \quad w = \kappa z\sqrt{3\lambda}$$

enables the reflected flux distribution to be obtained. More elaborate solutions including the source function are also available.

Whenever point or line sources are concerned, it is preferable to use the juxtaposition technique. Consider two diffusers A and B, placed together so as to form a composite diffuser of different shape, in which the total intensity is known. Let the intensity be required in A when B is removed. Since the total intensity in the composite diffuser is due to radiation which has always remained in A, together with radiation which has passed once or more through B, diffuser B provides a distributed source over the surface of A; if its strength be known, together with its effect in A, then the intensity in A alone can be found.

This method can be used, e.g., to obtain the intensity in a semi-infinite diffuser containing a line source by contacting with it a second semi-infinite diffuser, thus forming an infinite medium in which the total intensity is known.(7) These data, together with solutions for source-free semi-infinite media such as obtained above, can be used to secure a formal solution to the problem.

Methods (*a*) and (*b*) have enabled solutions to be obtained, numerically or analytically, for a wide range of problems, including (i) the sideways broadening of lines imaged on a projection screen; (ii) the contrast transfer properties of projection screens; (iii) the effects of diffusion in limiting the resolving power of photographic emulsions; (iv) reflexion by imperfectly dispersed diffusing media.

SPECTROSCOPY

A session devoted to various aspects of spectroscopy was opened by Mr. A. Walsh (Commonwealth Scientific and Industrial Research Organization, Division of Industrial Chemistry, Melbourne), who described the development of atomic absorption spectrophotometers for chemical analysis. He pointed out that the main limitation of emission methods of spectrochemical analysis is due to the occurrence of inter-element effects which necessitate the use of standards which are closely similar in composition to the sample for analysis. Since the proportion of excited atoms is usually negligible compared to the number of atoms in the ground state, such inter-element effects, insofar as they are due to variation in excitation conditions, can be circumvented by using absorption spectra.

Under conditions where the line widths are determined primarily by Doppler broadening, they will be of the order of 0·01 Å for temperatures up to 5000° K, and the profiles of such lines cannot be accurately recorded by any conventional spectrograph or monochromator. As a measure of the absorption coefficient, however, the peak absorption can be recorded. This has been achieved by producing sealed-off hollow cathode lamps which will emit resonance lines of the various elements under conditions which ensure that the line-width is small compared to the absorption line to be measured. For metals such as sodium, potassium, caesium and thallium, laboratory discharge lamps, such as the Wotan type, are satisfactory provided they are under-run to ensure that there is a minimum of self-reversal. The work to date has been restricted to the analysis of solutions, which are sprayed into the air supply of a Meker burner. In measuring the absorption of such flames, the light from the source is modulated before it reaches the flame, and a resonance line is isolated by means of a monochromator, the output of which is measured by a photomultiplier tube. The output of the latter is passed to an amplifier tuned to the modulation frequency, and thus any signals due to light emitted by the flame, which is not modulated, produce no signal at the output of the amplifier.

The type of monochromator which is used is governed by the fact that it must be capable of resolving the appropriate resonance line from all other lines. In many cases a filter is quite sufficient.

Possibly the most important result obtained to date is that, as would be expected, elements such as zinc and cadmium, with resonance lines in the extreme ultra-violet region, have the same sensitivity (0·1 parts per million) as sodium with its resonance line at the long-wave end of the visible spectrum. This is in marked contrast to emission spectra where the limit of detection of zinc, for example, is much lower than that of sodium, because the flame is not hot enough to excite an appreciable number of zinc atoms. For absorption, on the other hand, where we are concerned only with atoms in the ground state, this is of no consequence.

At the present state of its development the most serious limitation in the absorption method is due to the difficulty in atomizing various elements, e.g. aluminium, in a Meker flame.

Some preliminary work has been carried out on the design of atomizers for use with solid samples and on the development of a new type of filter which, it is hoped, will replace the conventional monochromator for this type of analysis.

Dr. R. G. GIOVANELLI (Commonwealth Scientific and Industrial Research Organization, Division of Physics, Sydney) spoke on the application of diffuse reflexion spectrophotometry to chemical analysis, a technique developed for rapid quantitative measurement of cytochrome in bacterial cells, but also of quite general application to absorbing substances in diffusing media. The method is based on the dependence of the reflectance R of a semi-infinite medium on the ratio α/σ of the absorption and scattering coefficients within the medium. The relation between R and α/σ is known theoretically for particles with various polar scattering diagrams; fortunately the variations in the shape of the R *versus* log α/σ curve are small enough to be neglected for biological work, so that it is sufficient to assume isotropic scattering.

Now α is the sum of contributions from the various absorbing components in the medium. If the contribution α_A due to component A has a spectral maximum (i.e. an absorption band), the medium has a corresponding spectral reflectance minimum. Its analysis is fairly simple if ΔR_0, the decrease in reflectance due to component A at the centre of the absorption band, is not too large and if, as is generally the case, the spectral variation of α_A takes the form of a damped resonance curve; for then it can be shown that the decrease in reflectance at a wavelength $\Delta\lambda$ from the band centre may be written as

$$\frac{\Delta R}{\Delta R_0} = \frac{1}{[1 + (\Delta\lambda/W)^2]}$$

where W is the band half-width. This relation can be used in sorting out the various ΔR_0 if there are several overlapping bands, and methods for doing this were described.

From ΔR_0, it is then easy to obtain α_A/σ from the relation between R and α/σ. The concentration of absorbing material is proportional to α_A, so that if, as usual, σ varies only slowly with λ, relative concentrations of components having absorption bands in not too distant spectral regions can be readily found, though independent calibration is required for absolute measurements. Methods for obtaining relative concentrations in different media were also described.

A short paper by Mr. D. A. DAVIES (Commonwealth Scientific and Industrial Research Organization, Division of Industrial Chemistry, Melbourne) described an interesti technique for the generation of accurate cylinders required the construction of diffraction gratings by the Merton meth After discussing the difficulties of preparing cylinders of t required softness by abrasive methods, he described a meth of diamond turning in which the diamond tool is support on a rubber-faced Michell type bearing carried by t cylinder itself. The relationship between the tool point a the cylinder being turned is controlled purely by this bearin The accuracy obtainable is independent of the lathe used rotate the cylinder and translate the tool along it. Spec care is taken to provide adequate lubrication and cooli of the bearing, and complete swarf removal is essential f good surface finish. Speeds of 500 rev/min with a cut 0·0001 in. and feed of 0·001 in. per revolution are use After two or three successive cuts, depending on the ma nitude of initial errors, the diameter of a $1\frac{1}{8}$ in. bar can held constant to ±10 μin. over 9 in. in the centre of a 17 length.

The surface finish is about ±1 μin. centre line avera with a waviness in the surface amounting to ±1 μin.

In other papers, Dr. A. DRESLER (Department of Labo and National Service, Melbourne) reviewed the present sta of the revision of the C.I.E. standard photometric a colorimetric observer, Mr. S. BAKER (Newcastle Universi College) described the testing of large gratings and Mr. J. MCNEILL (Commonwealth Scientific and Industrial Resear Organization, Division of Industrial Chemistry, Melbour described the testing and use of echelle gratings.

PHYSICAL OPTICS

In opening a session devoted to physical optics, Dr. W. STEEL (Commonwealth Scientific and Industrial Resear Organization Division of Physics, Sydney) reviewed t theory and measurement of contrast transfer functions (c.t.f. Imagery is said to be "isoplanatic" when small enough regio of the object are considered for the aberrations of the opti system to be sensibly independent of the position of t object point. Under these conditions, the classical treatme of the image of an incoherently illuminated object involv finding the illumination for a point image (the spread functio multiplying by the luminance at each object point and int grating over the object. But, by Fourier analysis, an obje can be considered as composed of sinusoidal variations space of different luminances and spatial frequencies. The components are imaged as sine waves with their contra reduced by a "contrast transfer factor." Asymmetric aberrations such as coma also cause a lateral shift of t component relative to the geometrical image; the c.t.f. then complex, its modulus denoting the contrast reducti and its argument the shift.

The change in specifying the luminance of the object fr a function of distance to one of spatial frequency th replaces a convolution integral by a simple product, althou a Fourier transform must be made if the illumination of t image is required against distance. The frequency approa is useful when communication theory is applied to opt and it also leads to considerable simplification when optical image goes through further processes such as phot graphy or diffusion at a screen since the c.t.f.'s of su independent processes can be multiplied together.

To study two dimensional objects a simple c.t.f. of single spatial frequency can be used if the reference axes a suitably rotated. This c.t.f. can be calculated as an aut correlation integral of the amplitude across the exit pu to a point source and is thus related to the aberrations ıe system. The area of integration and hence the function ish for a finite spatial frequency (the limit of resolution) ch depends on the aperture of the system. No detail igher frequency is resolved, the lens acting as a "low pass r." Exact calculations of the effects of aberrations have been carried out for the simplest cases of a defocusing astigmatism. But for any aberration, an approximate tment, valid down to 0·8 of the c.t.f. of a perfect system, be used to find tolerances based on the imagery of odic detail. For intermediate frequencies these tolerances slightly below the usual Rayleigh tolerances, but they rapidly for frequencies approaching either zero or the t of resolution. The effect of aberrations on the limit of olution is thus small, so that resolution measurements on n contrast charts, as well as only giving one point of the . curve, give little indication of aberrations unless they large.

magery with partially coherent illumination of the object be treated by analogous methods. But, as each spatial quency in the illumination at the image arises as the erence between each pair of frequencies in the amplitude the object, and no rotation of axes will reduce doubly iodic objects, the transfer factors depend on four spatial quencies. The treatment is more tedious but transfer ors, even in the presence of aberrations, can be found hout more mathematical difficulty than required for the responding incoherent case.

he experimental measurement of c.t.f.'s for use as an ective evaluation of image quality has received con- erable attention recently. Methods vary from direct asurement using sine or square wave transmission objects inding the spatial distribution in a line image and applying Fourier transform. The direct method appears preferable ce more light is available. A variation of this approach o use as a variable frequency sine wave object the fringes oduced by a shearing interferometer. Baker(8) has used a rror and beam splitter interferometer, while Dr. Steel ntioned that he was developing a polarization interfero- ter and also one based on crossed diffraction gratings. e moiré fringes produced by the latter should, if sufficiently form, enable white light c.t.f.'s to be measured; the other erferometers are limited to use with monochromatic light.

Mr. S. F. Smerd (Commonwealth Scientific and Industrial search Organization, Division of Radiophysics, Sydney) n spoke on the development of contrast transfer function ory in radio astronomy.(9) In this field observations suffer m much poorer resolution than in optics and the study of se effects has led to the development of c.t.f. theory. The lowing is an example.

Strip-like instruments have been used to study the distri- tion of radio brightness over the sun's disk. Strip scans taken in several directions and a two-dimensional distri- tion derived by Fourier transform theory. A point in strip scan is given by

$$f_S(x) = \int_{-\infty}^{+\infty} a(x' - x) f_L(x') dx'$$

ere $a(x)$ is the power response of the instrument (the ead function of optics) and f_L is a line scan of the true tribution in the object plane. The Fourier transform of the p scan is then

$$\bar{f}_S(\xi) = \bar{a}(-\xi)\bar{f}_L(\xi)$$

ere the transform $\bar{a}$ of the power response is the transfer ction of optics. The observed distribution will agree with the true value only if the transfer function is constant over the whole Fourier spectrum present in the object; this condition is not easily met in radio astronomy. It is interesting to note that, for the same cut-off, a transfer function constant up to this value gives the least mean square error, but not necessarily the "best image." The power response is the oscillatory function sin x/x and, when resolution is incomplete, such oscillations occur in the image near sharp features in the object. In practice it seems that, for observations with incomplete resolution, it is desirable to use an instrument whose transfer function falls gradually to zero at the cut-off frequency. For a radio telescope this means reducing the side lobes at the expense of widening the main lobe of the power response.

Dr. J. M. Cowley and Mr. A. F. Moodie (Commonwealth Scientific and Industrial Research Organization, Division of Industrial Chemistry, Melbourne) presented a new formulation of physical optics which can be applied to diffraction in small aperture multi-component systems of, for example, successive periodic objects or optical components. Expressions obtained for the wave function of a single lens agree with the Abbe or Rayleigh treatments and also give more general results.

If obliquity effects are neglected and a circular wave-front approximated by a parabola, the wave function at a point x on a screen at a distance R_1 from a point source on the axis is $\exp(-ikx^2/2R_1)$ where $k = 2\pi/\lambda$ is the propagation constant. If the point source is replaced by a coherent wave front $q_1(u_1)$ (in general complex) where u_1 is a co-ordinate on a line normal to the axis, the wave function at x becomes

$$\int_{-\infty}^{+\infty} q_1(u_1) \exp[-ik(u_1 - x)^2/2R_1]du_1 = \\ = q_1(x)^* \exp(-ikx^2/2R_1)$$

where the asterisk denotes convolution.

The effects of successive components are now described by multiplying the wave function by functions $q_n(u_n)$, these being referred to sets of parallel lines spaced at distances $R_1, R_2 \ldots R_n$ and each line being characterized by a co-ordinate u_n. The wave function is thus built up by convolution to represent passage from one line to the next, and by multiplication to represent passage through a component, thus:

$$\psi(x) = \underset{n}{[} q_n(x) \ldots \underset{2}{[} q_2(x) \underset{1}{[} q_1(x)^* \exp(-ikx^2/2R_1) \underset{1}{]}^* \\ \exp(-ikx^2/2R_2) \underset{2}{]}^* \exp(-ikx^2/2R_n) \underset{n}{]}$$

This is a restatement of Huygens' principle in a form suitable for development by Fourier transforms.

This development relies on the convolution and transform properties of $\exp(-iax^2)$, and the wave function can be manipulated by a symbolic algebra to give many equivalent expressions. These can differ in form and also in the space (direct or Fourier) in which the effect of any component is described: if all are to be described in Fourier space, one possible form is:

$$\psi(x) = K \exp(-ia_n x/2) \underset{n}{[} Q_n(-a_n)^* \ldots ^* \\ \underset{2}{[} Q_2(-a_2)^* \underset{1}{[} Q_1(-a_1)^* \exp(ia_1 x/2) \underset{1}{]} \times \\ \times \exp(ia_1 a_2 R_1/2k) \underset{2}{]} \times \ldots \times \exp(ia_{n-1} a_n R_{n-1}/2k) \underset{n}{]}$$

where $a_r = kx / \sum_{j=r}^{n} R_j$ and $Q_n(U_n)$ is the Fourier transform of $q_n(u_n)$. Usually the effects of groups of components may best be understood by comparing a number of possible reductions, and specific analytical details need only be introduced at the final stages.

This formulation has been applied, in electron optics, to the interaction of non-planar waves with periodic objects. Since the transform of a periodic object is a set of delta functions, the wave function for a point source reduces to a sum of exponentials, and this represents, at a certain set of planes, a magnified image of the object, the "Fourier images." Extended to slit or Gaussian sources, the treatment shows that the least resolvable distance depends on the sharpness of the edge of the source. These results have been demonstrated with visible light.

Dr. J. K. MACKENZIE (Commonwealth Scientific and Industrial Research Organization, Division of Tribophysics, Melbourne) concluded the session with an outline of communication theory in optics, giving a simplified account of Shannon's theory(10) as applied by Fellgett and Linfoot(11) to images formed by an optical instrument.

The fundamental problem of communication is to reproduce at one point either exactly or approximately a "message" selected at another point. The message can be any member of an initially prescribed set, and, when the probability of any particular selection is known, the information content H of the set is defined like entropy in statistical mechanics; for a discrete set with probabilities p_i, $H = \Sigma p_i \log_2 1/p_i$ "bits." For optical instruments the message corresponds to the object and its reproduction to the image.

For an isoplanatic instrument, Huygens' principle implies that the two-dimensional Fourier transform of the image brightness is limited to a finite region (of area B) of the frequency plane; B is determined only by the exit pupil and the coherence of the illumination. It follows that an image (of area A determined by the exit pupil) is completely determined by the values of the image brightness at a finite number, proportional to AB, of points. If a probability is associated with every possible selection of these AB values the corresponding information content or entropy of the set of all possible images can be calculated as above. If now the entropy of the noise (atmospheric fluctuations, say) is suitably subtracted, then the capacity of the instrument for transmitting information is defined as the greatest value of the resulting entropy when the associated probabilities range over all possible choices.

If the mean square fluctuations in brightness of the object set and the (Gaussian) noise are s^2 and n^2, the capacity of the instrument is $C = \frac{1}{2}AB \log_2 (s^2 + n^2)/n^2$ when the object is illuminated coherently and the noise is introduced prior to the exit pupil. Thus, the capacity of an instrument is independent of the aberrations present. This means that if one goes to enough trouble to analyse (decode) the image the effect of the aberrations can be removed. In general, the full capacity of the instrument will not be realized. However, the theorems proved by Shannon indicate that with suitably complex "coding" of the input signal the full capacity of the instrument can be effectively realized. Just what this coding entails in the case of an optical instrument is as yet unknown, nor is it clear to what extent subsequent decoding can replace initial coding.

INTERFEROMETRY

The final session was devoted to interferometry and was opened by Mr. C. F. BRUCE (Commonwealth Scientific and Industrial Research Organization, Division of Metrology, Sydney), who discussed the influence of the position and si of the effective source on the fringes produced in interfer meter systems using collimated light.(12, 13) The frin position is influenced by the small degree of obliquity in th incident light. If κ is half the phase difference between th interfering rays for a point source on the interferometer ax (which gives ideally collimated light), the fringe maxima minima in this case occur where $\kappa = n\pi/2$ ($n = 1, 2, 3, \ldots$ For a point source at an angle θ off-axis, the fringe maxim or minima occur where $\kappa = n\pi/2 + \kappa\theta^2/2$. The fring position is thus displaced by the phase angle $\kappa\theta^2/2$. Th fringe displacement for finite sources is obtained by co sidering the intensity distribution of the fringes produce from light coming from all points in the sources. For exampl the analysis shows that for a circular source with its cent on the axis and subtending on semi-angle α at the collimati lens, the fringe displacement is $[(\kappa\alpha^2/2) - m\pi)]/2$ whe $m\pi \leqslant \kappa\alpha^2/2 \leqslant (m + 1)\pi$ ($m = 1, 2, 3, \ldots$). If the cent of the source is at an angle β off-axis, the fringe displaceme $\delta\kappa$ is

$$\delta\kappa = \tfrac{1}{2} \tan^{-1}\left[\frac{U_1 \sin \kappa(\alpha^2 + \beta^2) - U_2 \cos \kappa(\alpha^2 + \beta^2)}{U_1 \cos \kappa(\alpha^2 + \beta^2) + U_2 \sin \kappa(\alpha^2 + \beta^2)}\right]$$

where
$$U_1 = (\alpha/\beta)J_1(z) - (\alpha/\beta)^3 J_3(z) + \ldots$$
$$U_2 = (\alpha/\beta)J_2(z) - (\alpha/\beta)^4 J_4(z) + \ldots$$

and $\lambda z/2\pi = \lambda\kappa\alpha\beta/\pi$ is the maximum variation in optic path length along rays from different parts of the sour Results for rectangular sources were also described.

Illustrative fringe displacement curves showed how th obliquity effects depend on the variation in path length fr different parts of the source. The curves show oscillat characteristics when this exceeds about $\frac{1}{2}\lambda$ and $\frac{1}{4}\lambda$ for circu and rectangular sources respectively.

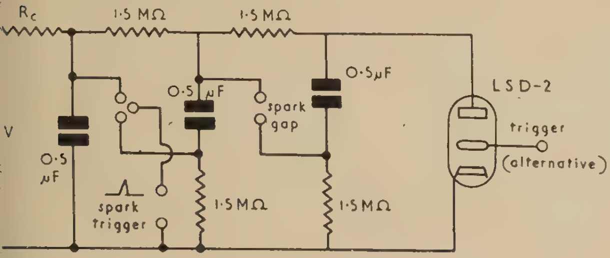
These effects are of particular importance in length inte ferometry and they are also applicable to interference micr scopy. The results account fairly well for some observation recently reported, on the measurement of step heights wi microscopes of different numerical apertures.(14) Referenc was also made to the significance of these obliquity effect in the use of channelled spectra for calibrating infra-r spectrophotometers.(15)

Dr. J. L. FARRANDS (Defence Standards Laboratorie Melbourne) showed that if in a Michelson interferomete one of the mirrors is replaced by a multiple-beam system asymmetrical fringes may be produced. The shape an intensity of the fringes depend on the reflectances of th surfaces in the multiple-beam system, and on the positio of the other mirror in the interferometer. Experimenta confirmation has been obtained both with optical an microwave interferometers.

Mr. B. S. THORNTON (Commonwealth Scientific an Industrial Research Organization, Division of Metrology Sydney) discussed the fundamental uncertainties which ar present when interferometry is used to resolve very fin detail on surfaces.

Mr. E. R. JOHNSON (Weapons Research Establishment Adelaide) gave a paper entitled "Microsecond sources fo interferometry." A light source was described which emitte light of very high intensity and for a period of between on and two microseconds. The factors which influence th choice of a suitable source were outlined and an impulse generator type of circuit (Fig. 1) was used to reduce th duration of flash of an LSD2 Arditron type of flash tube b a factor of two or three. A multi-layer dielectric interference filter was used to isolate the brightest lines of the argo ctrum and Fig. 2 shows an interferogram obtained by ng such a source.

r. C. K. Coogan (Commonwealth Scientific and Indusl Research Organization, Division of Industrial Chemistry, lbourne) read a paper entitled "The determination of the ical constants of ionic solids." Information about the tronic energy level bond structure of ionic solids can be ained from the optical properties of the solids. These perties can be deduced for thin films on a thick nonsorbing substrate by the measurement of the transmittance, lectance and metrical thickness of the films. The refractive ex and absorption constant are derived from these parameters using equations which have been obtained by modifying se of Mooney.(16)



ig. 1. Circuit of a 2 μs impulse generator for operating an LSD-2 flash tube as an interferometer source

Flash energy = 75 J minus losses in gaps.

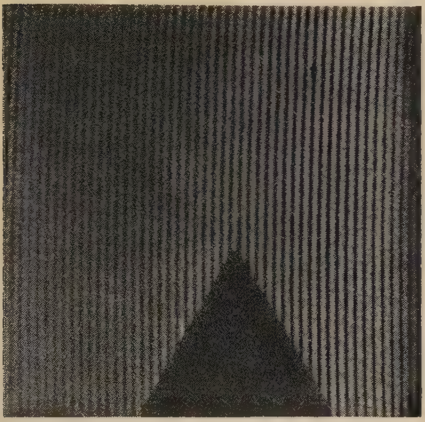


Fig. 2. The fringe pattern in a Mach Zehnder interferometer

xposure time: 2 μs; film: Ilford 5B52; original size 1 × 1 in.

These methods were applied to the case of zinc sulphide, l thin films were evaporated on to fused silica subtrates. e metrical thickness was measured by conventional ltiple beam interference methods. The transmittance and ectance were measured at given wavelengths, the latter ng obtained by comparison with a standard fused silica blank of known refractive index. The films could be cooled to liquid air temperatures.

Results were obtained for the absorption spectrum and dispersion curves of zinc sulphide, which show an anomalous dispersion centred around 3200 Å. A tentative interpretation indicates the presence of an excitor band centred on 3200 Å. The thermal shift of the absorption edge was also measured and is about -3×10^{-4} eV/° C.

A paper by Dr. R. Q. Twiss (Commonwealth Scientific and Industrial Research Organization, Division of Radiophysics, Sydney) entitled "An intensity interferometer" was read by Dr. J. P. Wild. This paper has already been fully reported.(17) A paper on "The measurement of small fringe displacements" was given by Dr. P. G. Guest (University of Sydney) and this has also been published.(18) Mr. E. R. Johnson (Weapons Research Establishment, Adelaide) also discussed briefly the conditions to be satisfied in two-beam interferometry.

C. F. Bruce
R. G. Giovanelli
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A high temperature microfurnace for the study of the devitrification of glass

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[*Paper first received* 13 *December*, 1955, *and in final form* 26 *November*, 1956]

The construction and operation of a microfurnace designed to combine a low thermal capacity with accurate temperature measurement is described. The specimen, which is approximately 1·5 mm in diameter, may be raised to a temperature of 1200° C in less than one minute and maintained to within ±2° C of the working temperature for several hours. For general work the specimen is viewed with a ×5 objective, though a ×10 objective, with a numerical aperture of 0·25, may be used for continuous observation up to 1000° C and for shorter periods at higher temperatures. In the instrument described the specimen is exposed to the air but conversion for work in a controlled atmosphere would be relatively simple.

Though primarily designed for the study of crystal growth from the melt, and the rapid delineation of phase equilibria diagrams, the apparatus has been applied to the study of the growth of single crystals, melting-point determinations and the investigation of phase precipitation in opal glasses. Special attention has been given to the photographic recording of experiments and an example of rate of crystal growth measurement using this technique is given.

In the study of the properties of glass, the investigation of devitrification is important both from the theoretical and practical aspects; the temperature at which the melt starts to crystallize and the rapidity with which growth takes place are limiting factors in the development of new glass-forming regions, and the interpretation of experimental results relating to these quantities will eventually yield further information as to the precise nature of the glassy phase.

When investigating a particular series of melts, the quantities determined are the liquidus temperature and the initial rate of crystal growth, as a function of temperature, for each precipitated phase. Quenching techniques(1,2) are usually employed. In general such measurements are tedious, they take a considerable time to complete, and, in many cases, the identification of the precipitated phases by optical and X-ray examination is difficult, due to the small size of the crystals and the number of phases present. As a means of overcoming these difficulties the possibility of using a high-temperature microscope to study crystal growth from the melt was considered.

An excellent description of the development of the high-temperature microscope is given by Saylor.(3) In general such instruments may be divided into three main classes. In the first, the specimen is mounted in a small furnace on the stage of conventional microscope and the optical system is protected by a water-cooled shield or jacket, one outstanding example is the instrument designed by Miss T. Stadnichenko and later modified by Saylor. The second class comprises those instruments which avoid high temperature gradients by the use of a relatively large furnace.(4) In the third class may be included unconventional designs such as that developed by Ordway(5) and recently modified by Welch;(6) in both these instruments the temperature measuring thermocouple also serves as the heating element, and due to the small power dissipation of such instruments it is possible to use medium powered objectives at temperatures up to 1750° C with the minimum of shielding.

To be suitable for the study of crystal growth from the melt, a high-temperature microscope must fulfil certain requirements: since the crystals examined rarely exceed 100 μ in length, the resolution of the optical system should be relatively high; for photomicrography a large proportion of the magnification should be supplied by the objective; the specimen must also be supported above its softening temperature so that the surfaces are relatively plane to permit examination under transmitted light; the thermal capacity of the furnace must be low and the heating supply flexible to allow rapid changes to be made in the temperature and a high order of accuracy in temperature measurement must be obtained combined with temperature stability over long periods.

Since a low thermal capacity was desired, the choice was restricted to either a type of microfurnace or a model similar to that constructed by Welch. After preliminary experiments both were found to possess certain unfavourable characteristics from the point of view of the work to be undertaken and the present model was developed.

DESCRIPTION OF THE APPARATUS

The furnace. The furnace is shown diagrammatically in Fig. 1. Basically it consists of two plates of platinum 10% rhodium foil, 4 cm long, 3 cm wide and 0·05 mm thick mounted parallel to one another 7 mm apart. One end is closed by a platinum plate 1 mm thick, which serves as the electrical connexion between the plates, while a spring attached to this plate holds the furnace under a slight tension to prevent sagging at high temperatures. At the other end the plates are welded to two platinum bars 3 mm square and 10·6 cm long, clamped to four heavy copper terminals projecting from a platform of Sindanyo insulating material which replaces the normal microscope stage. These terminals are adjustable so that the axis of the furnace may be alined with the optical axis of the microscope. Water-cooled plates attached to the objective and the condenser, shield the upper and lower surfaces of the furnace from draughts and protect the optical system, while carbon blocks resting on the platform completely enclose the sides of the furnace. A small aperture in the block on the left-hand side allows the specimen to be moved into the centre of the heating element. To protect the surfaces of the lenses from contamination by atile components of the melt the openings in the water-led plates are closed by thin glass cover slips; these are ally changed at the end of each experiment. The optimum of the apertures in the heating plates may be calculated n the characteristics of the lens and the height of the ace; thus if the mean refractive index is taken as unity, radius of the apertures is given by:

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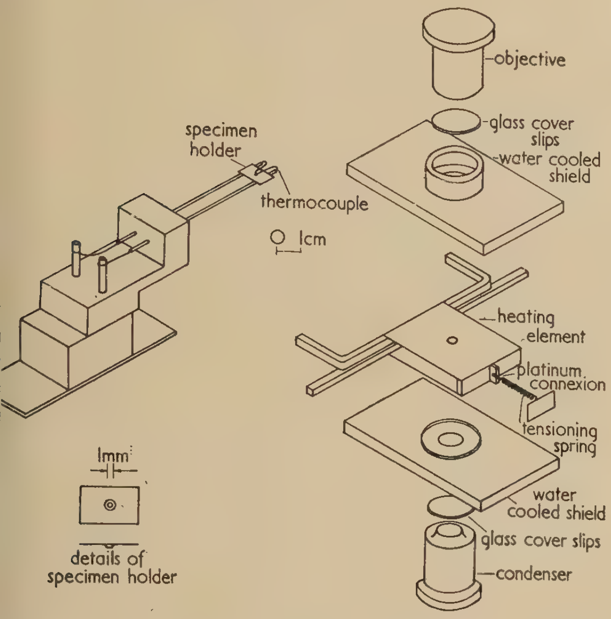
$$r[1-(h/d)] + hN/(1-N^2)^{\frac{1}{2}}$$

ere r is the radius of the cell in the specimen holder, $2h$ is height of the furnace and d and N are the working ance and the numerical aperture of the objective.



ig. 1. Microfurnace heating element and cooling system

The specimen cell is formed in a small rectangle of platinum l and carries a specimen approximately 1·5 mm in diaeter and 0·5 mm thick. The holder is supported by two es of fused alumina, 1 mm in diameter, projecting from a ck of Sindanyo mounted on a microscope slide, these es also carry the thermocouple leads. A precision tical slide, mounted on the left of the specimen, carries mechanical stage previously fitted to the microscope. is arrangement allows the specimen to be adjusted in three ections relative to the furnace, the travel in the lateral ection being sufficient to enable the specimen to be comtely withdrawn from the heating element.

he power supply. The circuit diagram is given in Fig. 2. e main heating current is supplied by a stepdown transmer fed by a 230 V variable transformer, while the fine nperature setting is obtained by feeding an additional ltage (±20 V) into the primary circuit from a second riable transformer and a stepdown transformer.

o improve the temperature stability of the instrument d to eliminate long term temperature drift, a temperature ntroller of the continuous balance type is fitted to operate fine control variable transformer. With a furnace of low rmal capacity, as in the present case, the response to a all temperature variation is rapid and highly damped. A e-of-flow operated switch protects the optical system from y failure in the supply of water to the cooling system.

The optical system. A conventional optical system is used with one exception; due to the short working-distance of the normal Abbe condenser it was not possible to use this type with the microfurnace. Accordingly the sub-stage was modified to take an objective of the same power as the one used for observing the specimen. This symmetrical optical arrangement is very satisfactory in practice. The sub-stage also carries an iris-diaphragm and holders for the filters and for the analyser when polarized light is used. The ×10 objective gives good results for continuous observation at temperatures up to 1000° C and for short periods up to 1200° C. For continuous observation at temperatures up to 1200° C, and for most work where the full resolving power of the instrument is not required, a ×5 objective has proved quite satisfactory.

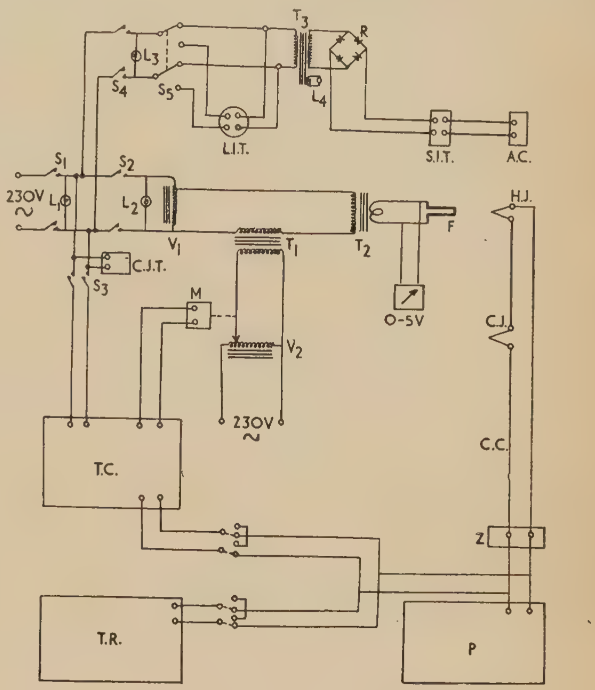


Fig. 2. Power supply and thermocouple circuits

V_1, autotransformer, coarse temperature setting; V_2, autotransformer, fine temperature setting; T_1, 10 : 1 stepdown transformer 0·5 kVA; T_2, 50 : 1 stepdown transformer, output 5 V, 1 kVA; *F*, furnace; *T.C.*, temperature controller; *M*, balancing motor; H.J., thermocouple hot junction; C.J., thermocouple cold junction; *C.J.T.*, cold junction thermostat; *C.C.*, compensating cable; *Z*, thermocouple zone plate; *T.R.*, temperature recorder; *P*, potentiometer; S_1–S_5, switches; L_1–L_4, warning lights; T_3, stepdown transformer; *R*, full-wave rectifier; *L.I.T.* long interval timer; *S.I.T.*, short interval timer; *A.C.*, auto-camera 12 V d.c.

TEMPERATURE MEASUREMENT

Measurement of the specimen temperature is by means of a platinum/platinum–10% rhodium thermocouple, constructed of wire of diameter 0·005 in., used in conjunction with a potentiometer. Originally two thermocouples were used, one for temperature measurement and the other for a control element, but later it was found more convenient to use one couple for both functions. If the controller is near the balance condition only a slight error is involved in using this arrangement. To remove the error entirely the controller may be momentarily switched out of circuit as the potentiometer reading is taken.

For both these circuits a reference temperature, constant to within 0·1° C, is provided by a cold-junction thermostat. For accurate measurement of temperature the thermocouple junction should be in intimate contact with the specimen: in those cases where the melt attacks platinum the junction should be placed, in contact with the holder, as close as possible to the edge of the melt and a correction determined in a separate experiment. Melting point determinations carried out under these conditions show that the necessary correction is only a few degrees.

PHOTOGRAPHIC EQUIPMENT

The camera finally adopted for this instrument was a 35 mm Auto-camera (by G. D. Shackman and Co.). The sequence of operations is electrically controlled by a timing unit which allows the interval between exposures to be varied from 2 to 50 s. To extend this interval, provision was made to control the electrical supply to the timing unit with a process-timer. By varying the pulse length, pulse interval and repetition frequency of the camera, single exposures or groups of exposures may be taken at intervals of up to 60 min. An observation eyepiece incorporating a beam-splitting unit allows the progress of the experiment to be followed without disturbing the operation of the camera.

GENERAL

A photographic stand is made for use with the camera and this supplied an excellent base for the instrument as a whole. A sheet of Sindanyo, 33 in. square, bolted to the heavy metal base of the stand and supported at the corners, provided a suitable platform for the microscope and ancillary equipment. The camera itself is held by a bracket clamped to a vertical tube 2 in. in diameter and is rigid and free from shake.

With the exception of the final current transformer, which is mounted on the base, the power and control circuits for the furnace and the camera are housed in a separate cabinet. A projection screen is used to eliminate fatigue to the operator during long periods of observation. The design is simple, a small prism mounted over the eyepiece turns the light into the horizontal plane, it is then reflected by a front surfaced aluminized mirror so as to form the image on a screen, 9 in. square, mounted on the right-hand side of the microscope. When not in use the apparatus may be moved to the back of the stand to allow the camera to be lowered into position. Two microscope lamps are normally employed. For visual observation and some photography, a normal ribbon filament lamp is sufficient, while for projection purposes a 250 W compact-source, mercury arc lamp is preferable. This lamp is invaluable for photographic work in that fine-grain films may be used with exposure times as low as 1/250 s.

In setting up the apparatus the following procedure is adopted: the furnace is clamped lightly in position and set by eye both for height and alinement, and a diaphragm with a small hole in the centre is fitted over the mirror. Using a low-power objective, the condenser is alined so that the image of the diaphragm occupies the centre of the field. By focusing the upper and lower furnace apertures the heating elements are adjusted for alinement; the elements are then checked for parallelism and separation, and if any adjustment is found necessary the procedure is repeated.

MEASURING TECHNIQUES

When the rate of crystal growth is low (0·1 – 1 μ/min.) the crystal dimensions may be measured with the aid of a micrometer eyepiece, though less strain is placed on the operator if the projection system is used. For higher rates of growth photographic recording should be employed and care should be taken in the preparation of the specimen to avoid curvature of the surfaces which results in a loss of definition and uneven illumination of the field. Curvature of surfaces may also be lessened by a suitable choice of holder; the type usually used is a small, conical cell formed in a piece of platinum foil, though for very fluid melts platinum gauze with circular perforations 1·1 mm in diameter reduces the tendency for the material to flow through the holder.

Liquidus temperatures are measured by finding two temperatures bracketing the point of zero rate of growth and then reducing the interval between them until the desired accuracy is reached; a value to within ±5° C may be found within a few minutes using this method. Alternatively, for certain types of crystal, rates of growth and solution are measured and the temperature of zero rate of growth found by interpolation. The ultimate accuracy of both methods is approximately ±2° C.

PERFORMANCE

Details of the performance are given in Table 1. Temperature variation is composed of a short period oscillation and a drift of the mean temperature; the latter is removed completely by the temperature controller while the former is reduced to ±2° C.

Table 1. *Operating characteristics*

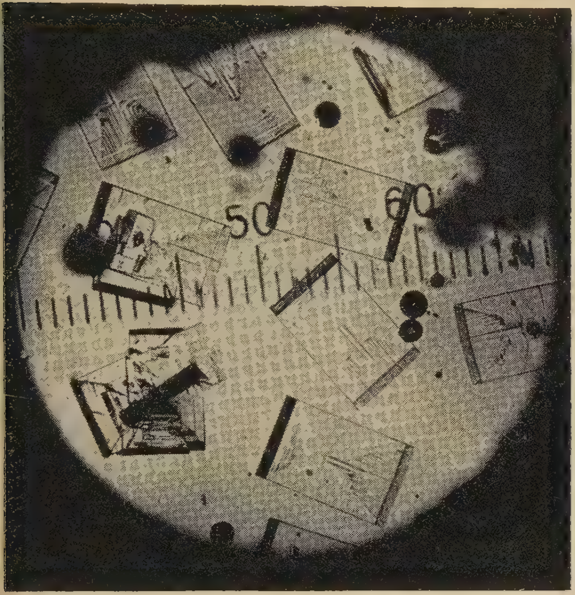
Furnace resistance	0·017 Ω at 400° C
	0·03 Ω at 1000° C
Maximum operating temperature	1250° C
Power dissipation	29 W at 400° C
	420 W at 1200° C
Temperature stability at 1000° C;	
without temperature control,	±3° C. Period approx. 30 s
	±2° C. Up to 40 min
with temperature control,	±2° C. Period approx. 30 s
	±1° C. Several hours
Rate of change of specimen temperature,	
20–1200° C	Less than 1 min
1200–100° C	30 s
Repeatability of liquidus temperature measurements,	±2° C

The accuracy of temperature measurement was checked at several temperatures by the determination of known melting points; the values quoted in Table 2 are the average values both for solution and crystallization of the material in the vicinity of the thermocouple junction. The temperature gradient across the specimen was measured by arresting the change of state in various parts of the field.

Table 2. *Temperature calibration*

ubstance	*Average melting point (measured)* (°C)	*Range of readings* (°C)	*Temperature gradient in specimen* (°C)	*Melting point (quoted)*(5) (°C)
KCl	772	1	3	770
NaCl	804	2	3	800·4
Na_2SO_4	887	2	4	884
K_2SO_4	1071	1	2	1069

espite the fact that the departure from normal viewing ditions is considerable, the definition of the image is good; example of the results which are obtained is shown in . 3, and a typical example of a rate of crystal growth asurement is given in Fig. 4 for two crystals of lead borate wing in the same sample. The discontinuity in the lower of growth for crystal (1) was apparently due to the leation of another crystal on the upper face of the large



ig. 3. Photomicrograph showing crystals of lead orate ($PbO.2B_2O_3$) at a temperature of 710° C (1 scale division is equal to 31·5 μ)

stal, this resulted in the formation of a step and the ferential growth of one of the longer faces.

elch(6) has commented on the possibility of errors being roduced into the measurement of liquidus temperature ng microfurnace technique due to the small samples ployed: no such effect has been observed in the measurent of liquidus temperatures, though certain discrepancies e been found between rates of growth measured using microfurnace and normal quenching techniques. In se cases, excellent agreement is found except in the vicinity the maximum rate of growth where the microfurnace lts were invariably higher. This is probably due to the that nucleation in this region is sporadic and no allowance ade for this in the quenching technique.

ther applications of this instrument include meltingnt determination, the investigation of phase precipitations opal glasses and the growth of large, single crystals for optical and X-ray examination. In the latter case single crystals up to 1 mm across have been prepared.

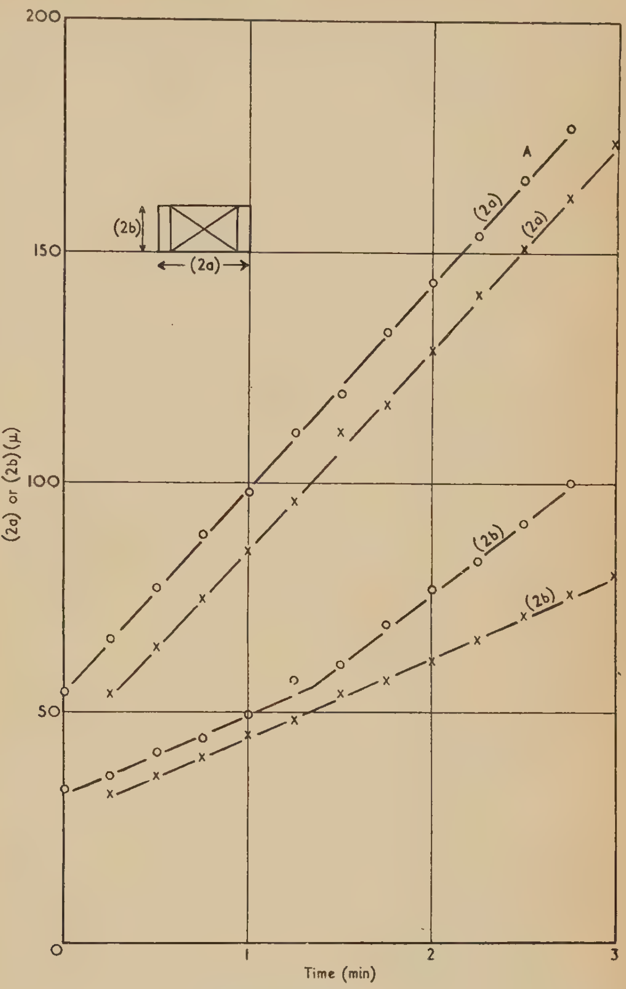


Fig. 4. The linear dimensions of two crystals of lead borate against time at 723° C

o, crystal (1).
x, crystal (2) (time axis displaced by 15 s).

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The author wishes to thank the Directors of Messrs. Pilkington Bros. Ltd. for permission to publish this paper.

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A photographic recording microphotometer

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[*Paper first received* 30 *July, and in final form* 13 *December*, 1956]

A simple method of converting a non-recording microphotometer into a single-beam recording instrument of good discrimination and high speed is described. The existing photovoltaic cell of a Hilger microphotometer is replaced by a cadmium selenide photoconductive cell. This increases the sensitivity to such an extent that the long period galvanometer is replaced by a much less sensitive, more robust, and very short period galvanometer. By connecting a large ratio reduction gear between the plate slide of the microphotometer and a large photographic drum the instrument is converted to a recording microphotometer of good discrimination, large magnification and high speed, capable of handling a wide range of photographic densities.

By taking advantage of the high sensitivity of the new Hilger and Watts cadmium selenide photoconductive cells, a non-recording Hilger microphotometer was converted into a useful single-beam recording instrument at relatively little cost. It was shown at the Physical Society Exhibition in 1955, and has been used in these laboratories for the last two years with every satisfaction.

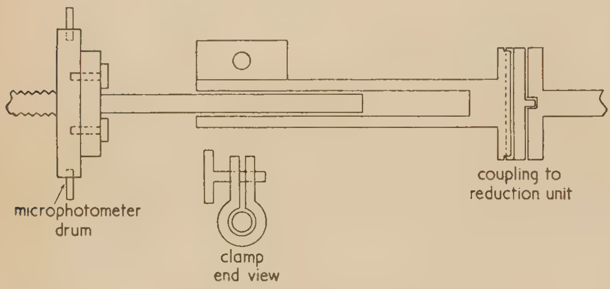

Fig. 1. Driving shaft

When operating under a voltage of 1·0 V, the new ce gives about 200 times the current obtained from the seleniu photovoltaic cell usually fitted. For this reason the origin high-sensitivity 2·5 s period galvanometer can be replace by a robust reflecting galvanometer of 0·2 s period and lower sensitivity, but which, nevertheless, gives a deflexi of 400 mm at 90 cm through clear glass, with 1 V across th cell and an exploring slit of 0·5 × 0·06 mm. It should noted that up to 50 V across the cell may be used wi suitable precautions and, since the cell for a given lig intensity acts like a pure resistance, this would produce further current gain of fifty times if required.

The conversion to a recording instrument was made constructing a photographic recording drum, and coupli it to the original instrument through a 40 : 1 reduction ge driven by a small electric motor.

A shaft accurately fixed on to the driving drum of th microphotometer slides into a larger hollow shaft with split end and a clamp (Fig. 1). This is connected at th other end through a self-alining coupling to the fast side the reduction gear. By this means the main slide of th

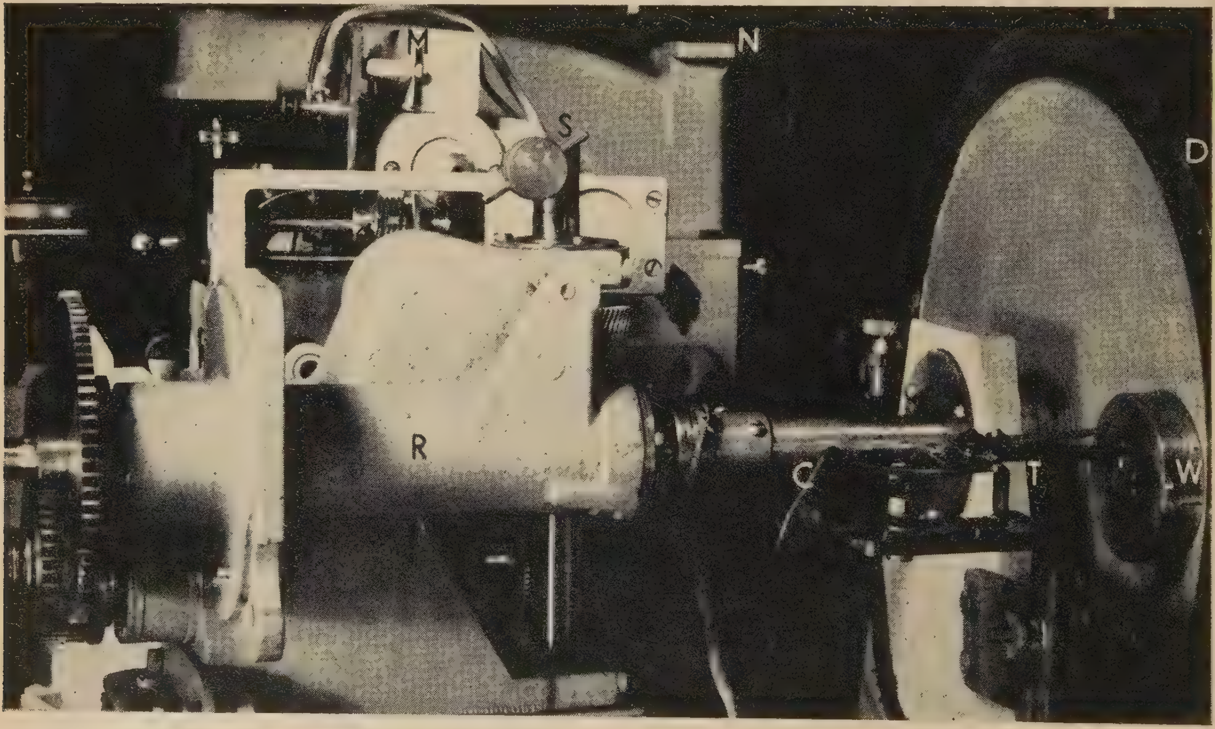

Fig. 2. Arrangement of reduction unit, recording drum and microphotometer

rophotometer can be easily adjusted in any convenient ition.

The recording drum *D*, Fig. 2, was made from a hollow l tube about 26 cm diameter, 40 cm long, with welded-on l plates through the centres of which a driving shaft was d. Both shaft and drum were machined at one operation. was then mounted on ball bearings and coupled up to the w end of the reduction unit by another anti-backlash self- ning coupling *C*. A small adjustable weight *W* fixed to of the end plates enabled the drum to be accurately anced. A short rod protruding from the balance weight ens the contact arm of a telephone switch *T* after a nplete rotation of the drum, so cutting off the current to driving motor and preventing over-running and damage the 2 cm long ½ mm pitch precision screw of the micro- otometer. The switch slides back manually to remake ntact and permit clearance of the rod. A simple clamping angement was fitted to the drum to hold the recording per firm and taut.

For the author's purpose a magnification of about forty nes was required, which necessitated a drum of some 80 cm cumference to accommodate the 2 cm traverse of the crophotometer slide, and a 40 : 1 reduction ratio between microphotometer and the drum. The reduction unit *R* nsisted of a combination of a 4 : 1 anti-backlash direct aring with a 10 : 1 epicyclic gear train, all of high precision, ected from an unused obsolete pattern predictor. The icyclic gear train could be made to run "loose" by slacking the clamping screw *S* round the "free" vertical shaft of epicyclic gear, thus effectively uncoupling the drum from microphotometer *N*, and enabling the position of the um to be independently adjusted easily and rapidly with microphotometer coupled up to the fast side of the duction unit.

The drive to the reduction unit is by a small 24 V 0·3 A otor *M* running at approximately 4500 rev/min, housed above and slightly to one side of the unit and coupled to it by a double worm train of 38 : 1 and 12 : 1, giving an overall reduction of 456 : 1 and a resultant plate speed of 5 mm/min. Precision gearing is not necessary here, and part of this was constructed from Meccano gears. The high speed of the motor, combined with the inertia of the recording drum and microphotometer slide, produced very smooth and even running of the whole instrument. There is, of course, no particular merit in the exact form of gearing used and anyone making a conversion similar to that described would use whatever gearing was available.

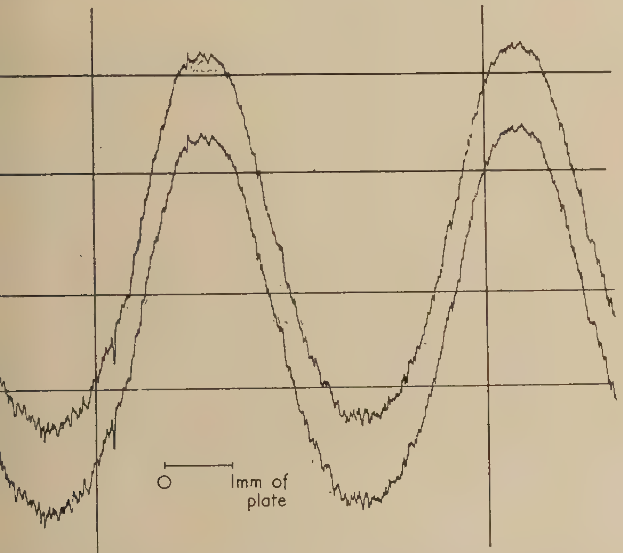

Fig. 3. Microphotometer records. Lower trace shows a repeat using a different zero

Magnification ×40.

With a constant voltage transformer for the microphotometer lamp, and an accumulator for the photocell potential, accurate and reproducible results were obtained, as is shown by the section of a typical record in Fig. 3. The lower trace is a repeat with a different zero, and demonstrates the high degree of reproducibility and discrimination achieved. The high-frequency variation, of the order of 1/100 mm on the plate, due to granularity in the fine grain plate is reproduced with high fidelity. In Fig. 4 this high-frequency "noise" has been removed with no reduction in amplitude by shunting the galvanometer with a 500 μF condenser. Alternatively, a suitable galvanometer of longer period can be used, but the use of a condenser gives greater flexibility. The horizontal lines are made by focusing fixed beams on to the drum, and the vertical lines by allowing the galvanometer spot to sweep across the stationary drum.

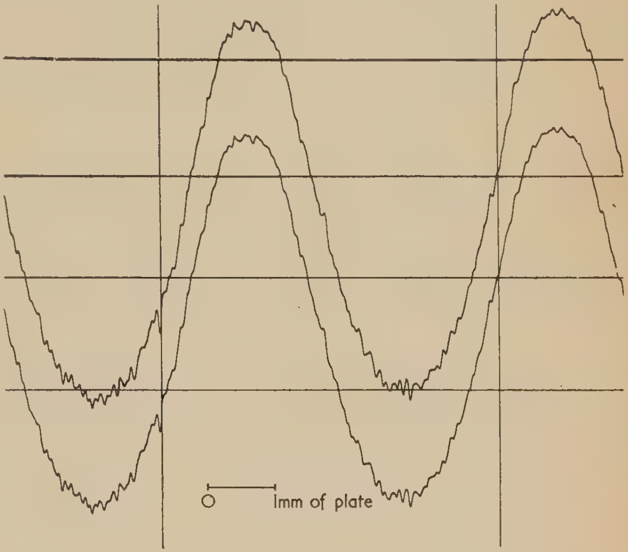

Fig. 4. As in Fig. 3, but with a 500 μF condenser across the galvanometer

Magnification ×40.

ACKNOWLEDGEMENTS

I am indebted to the Leverhulme Trustees for a two-year research grant which resulted in the construction of this instrument as a by-product of the main research programme. I would also like to thank Mr. Abbott of the works department for his skill and assistance in the constructional work.

The floating-zone melting of refractory metals by electron bombardment

By A. Calverley, B.Sc., M. Davis, Ph.D.,* and R. F. Lever, M.A.,* Services Electronics Research Laboratory, Baldock, Herts.

[*Paper first received* 12 *November, and in final form* 17 *December*, 1956]

An apparatus which produces floating liquid zones in vertical rods of refractory metals is described. Movement of the zone along the specimen can purify it in three ways, namely, outgassing on vacuum fusion, evaporation of volatile impurities, and segregation of impurities in the liquid zone. Traversing speeds of approximately 1 cm/min have been used and the vacuum maintained between 10^{-5} and 5×10^{-4} mb. Power requirements are about 400 W or less. There is a theoretical upper limit of approximately 1 cm on the diameter of a specimen and a practical size limit on its length. Specimens as low as 2 mm in diameter have been zoned. After zoning, many specimens are found to be single crystal.

The purification of a wide range of materials can be achieved by zone melting,(1) in which the repeated traversal of a specimen by a molten zone segregates at one end of the specimen those impurities which are preferentially soluble in the liquid. To avoid crucible contamination, the technique of floating-zone melting(2) was developed, the molten zone being held stable in a vertical rod by surface tension.

Hitherto, the method of heating has either been by high-frequency induction(3) or by radiation.(4) The authors have substituted electron bombardment as a means of heating,(5) using the specimen as an anode and surrounding it with an annular cathode. This has the advantage that the heat input is highly concentrated, making it possible to floating-zone melt tungsten and the other refractory metals where power requirements would otherwise be prohibitive. Control of the power is simple and the method is applicable to small diameter specimens.

With many metals, traversal of the specimen by a molten zone usually produces a single crystal, no seed crystal being required to initiate single crystal growth. Thus, single crystals of the refractory metals can be grown with three processes contributing to their purity, namely: (1) outgassing on vacuum fusion; (2) evaporation of volatile impurities; and (3) zone refining.

SIZE LIMITATIONS

While the length of specimen depends only on the physical side of the apparatus, there is a maximum diameter which can be zoned(6,7,8) depending on the surface tension and density of the liquid metal. Typical figures for maximum diameter are: silicon 1·0 cm, tungsten 0·5 cm. There is no theoretical lower limit to diameter, but this is governed by practical difficulties. For a specimen of given diameter, there is a maximum length of zone of the order of the diameter, which can be supported by surface tension. Above this length, the zone becomes unstable and collapses. (See also the appendix.)

DESCRIPTION OF THE APPARATUS

Vacuum system. A vacuum of the order of 5×10^{-4} mb is required for electron bombardment. This is obtained in a continuously pumped system, using a 2 in. two-stage mercury diffusion pump (by Edwards High Vacuum Ltd.) backed with a rotary oil pump and trapped with a Pollard conduction trap.(9) Mercury diffusion pumps are used in preference to oil diffusion pumps to avoid carbon contamination caused by oil vapour cracking on the hot specimen. The bombardment chamber is a flanged tube of Pyrex glass 20 in. high × 6 in. internal diameter. A flap valve is incorporated which enables the chamber to be let down to air and subsequently evacuated without switching off the vacuum pumps. Rubber O-ring sealing rings are used throughout. The pressure is measured by an ion gauge sealed into the side of the chamber. The initial pressure of the system is 4×10^{-6} mb and the pressure during operation between 2×10^{-5} and 5×10^{-4} mb, the estimated pumping speed being 20 l./s.

Cathode arrangement (Fig. 1). It is found convenient to earth the specimen and run the cathode at a high negative voltage. The whole electrode system is hung from a stainless steel top plate *A*, enabling the initial adjustments to be made away from the vacuum apparatus. The cathode *B* [see also

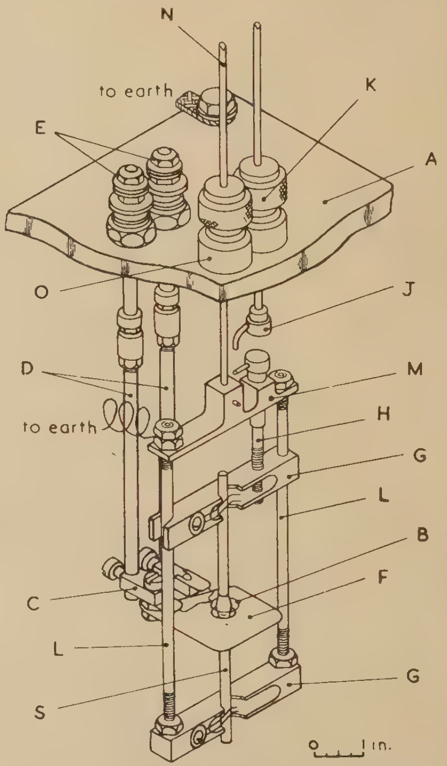

Fig. 1. The electrode system. (Top focusing plate not shown)

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g. 2(*a*)] is made from 0·010 in. diameter plain tungsten re and can be let down to air after operation without rming its emission properties. This shape of cathode is ble to distort and short at its cross-over point, and has to reset after outgassing. The alternative design shown in g. 2(*b*) retains its shape well but requires larger current ds and electrodes. The cathode is spot welded to nickel tantalum U-shaped tabs which are bolted to mild steel ocks *C*. These blocks are screwed to two vertical silver el rods *D* fixed to Edwards type 7A vacuum-sealed elecodes *E* which take the cathode current through the top ite. Each of the mild steel blocks carries a molybdenum or ntalum focusing plate *F* which limits the vertical spread of ctrons from the cathode and results in considerable onomy of power. The gap between the plates is about n. The size of the holes in the plates is the smallest possible, mpatible with clearance between the plates and the specimen ring operation. The diameter of the cathode is about $\frac{1}{4}$ in. ger.

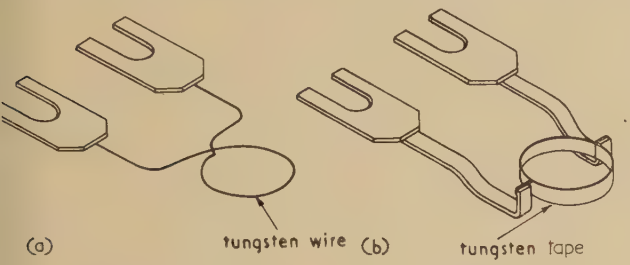


Fig. 2. Alternative designs of cathode

(*a*) 0·010 in. diameter tungsten wire.
(*b*) 2 mm × 0·001–0·002 in. tungsten tape.

Support and traversal of specimen. The specimen *S* is held each end by 0·030 in. diameter tungsten wire springs in grooves cut into mild steel blocks *G*. This permits pansion and contraction of the specimen during operation. e V-blocks are recessed to provide better location of the ecimen and to reduce the thermal contact. The upper ock can move relative to the lower by rotating the screw *H*, the connector *J*, attached to the rod passing through a rotary shaft O-ring vacuum seal *K*. This movement allows a degree of control over the shape of the floating zone and facilitates joining two specimens together.

The V-blocks are mounted on silver steel rods *L*, supported from a mild steel block *M*. The whole frame is mounted on a $\frac{1}{8}$ in. diameter silver steel rod *N* passing through a rotary shaft O-ring vacuum seal *O* in the top plate. Linear motion of this rod allows movement of the specimen relative to the cathode. This can be done by hand, but for uniform slow speeds a simple winch comprising a geared motor and reduction gearbox is used, giving traversing speeds of 1·25 cm/min or 2·25 cm/min. These speeds are much faster than those normally used for crystal growing and zone refining.

The alternative method of moving the zone is to fix the specimen and traverse the cathode. An apparatus has been built using this method which has the advantage of greater length of travel for a given height of bombardment chamber. The construction of the traversing equipment and cathode holder, however, is more difficult. The problem of the moving cathode leads was solved by using multiple thin copper tapes. Unlike the simple apparatus there is no longitudinal movement of any shaft through the top plate and this may be advantageous where high vacuum conditions are required. The second apparatus also incorporates means of rotating the upper half of the specimen during operation, but this seems to offer little advantage. With specimens that can be viewed continuously (see section under visibility) the moving cathode can be disadvantageous in that the zone is not opposite the viewing port throughout the operation.

The frame and cathode are surrounded by an earthed nickel cylinder approximately 5 in. diameter × 6 in. long. This prevents accumulation of electric charge on the glass chamber and also acts as a radiation shield. Two silica windows are let into the nickel cylinder for viewing purposes.

Electrical system. The h.t. supply which is of standard design, is half-wave rectified, unsmoothed and capable of supplying up to 2·5 kV, 500 mA. It consists of a Variac supplying a 5 kV, 500 mA transformer and a type GU 21 half-wave mercury vapour rectifier tube. A relay is incorporated to cut out in case of overload. The cathode is supplied from a transformer delivering up to 10 A at 14 V

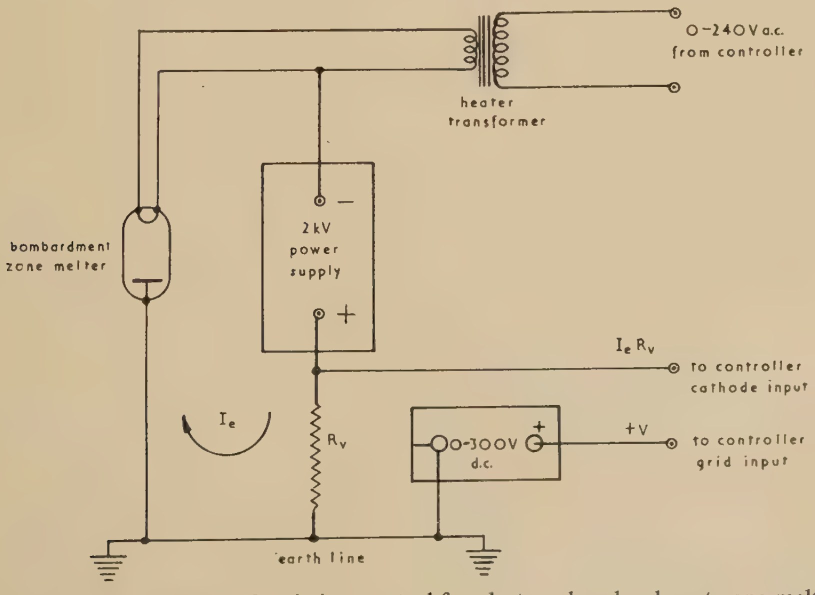


Fig. 3. Block schematic of emission control for electron bombardment zone melter

from a Variac-controlled mains input. As described below, it is very desirable to have some form of automatic control over the power input. There are two possible methods:

(i) emission control, in which the bombardment current is kept constant by automatically adjusting the cathode temperature;

(ii) supply of the h.t. from a constant current source. In this, the bombardment current is kept constant by adjusting the bombardment voltage.

The authors found it convenient to adopt the first method. It has, however, the disadvantage that the speed of response is limited by the thermal lag in the cathode. The second method, in which a current limiting valve is placed in series with the h.t. supply, would have an extremely rapid response.

The principle of the control system is illustrated in Fig. 3. The current to be controlled, I_e, develops a voltage I_eR_v across a resistor R_v connected between the positive end of the 2 kV power supply and earth. Voltage I_eR_v is arranged to be a few hundred volts in magnitude, and this is compared with the output V of a variable 0–300 V d.c. supply, the difference being fed into the controller, as shown in Fig. 3. The controller maintains this voltage at a minimum by varying the current through the heater transformer, which in turn alters the cathode temperature, adjusting I_e so that $I_eR_v = V$.

The mechanism of the controller may be readily appreciated by reference to Fig. 4. In series with the Variac T_1 and the primary of the heater transformer is the primary of the second transformer T_2. Across the secondary of T_2 are connected two thyratrons as for full-wave rectification. When the thyratrons are not firing, the current through the cathode is determined by the impedance of T_2, which acts as a very high inductance so that the cathode is barely raised to red heat. When the thyratrons are firing, however, T_2 represents a resistive impedance of only a few ohms, and the cathode current is determined mainly by its own impedance. Variac T_1 is set so that under this condition the cathode is copiously emitting. The input signal $V - I_eR_v$ then adjusts the firing time of the thyratrons so that the power supplied to th cathode maintains I_e at the desired value.

Three points of detail in the circuit may be noted:

(1) a small alternating voltage is applied to the thyratron grids, leading the anode voltage in phase by $\pi/2$. This is to increase the range of control;(10)

(2) the time constant on the input can be varied over the range 1/20 to 5 s to prevent hunting due to the therma lag in the cathode. The time constant is set as short as possible, consistent with the system not oscillating;

(3) if the h.t. supply is cut, I_e becomes zero and the thyratron input becomes equal to V which is large and positive. The thyratrons then fire over their entire range, with some risk of holding the cathode temperature at an excessively high level. A pair of contacts on the h.t. overload relay is therefore placed in series with the primary windings of T_2 so that in the event of the h.t. cutting out, the cathode heater supply will also fail.

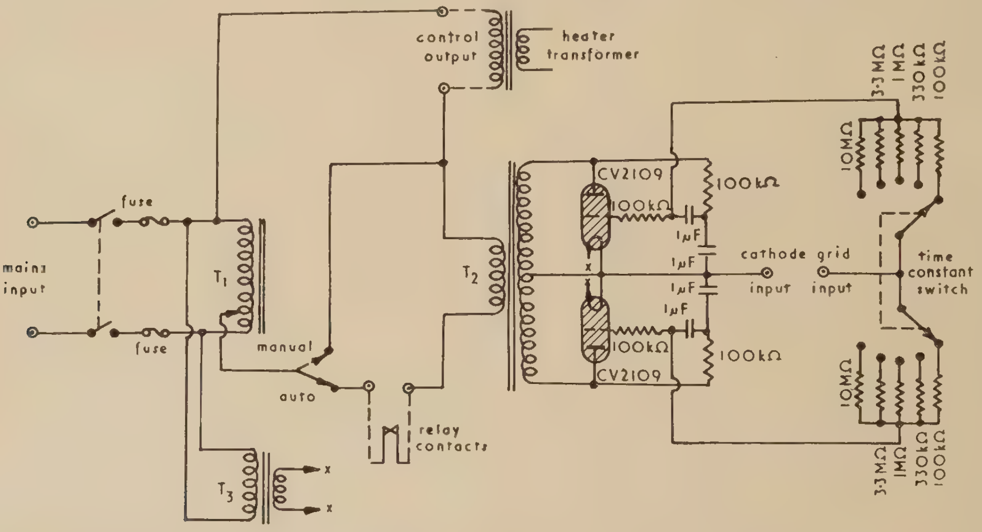


Fig. 4. Emission control circuit for electron bombardment zone melter

T_1 = Variac type 200 CUH.
T_2 = primary 0–240 V, secondary 350–0–350 V, 500 mA.
T_3 = primary 0–240 V, secondary 0–5 V, 5 A.

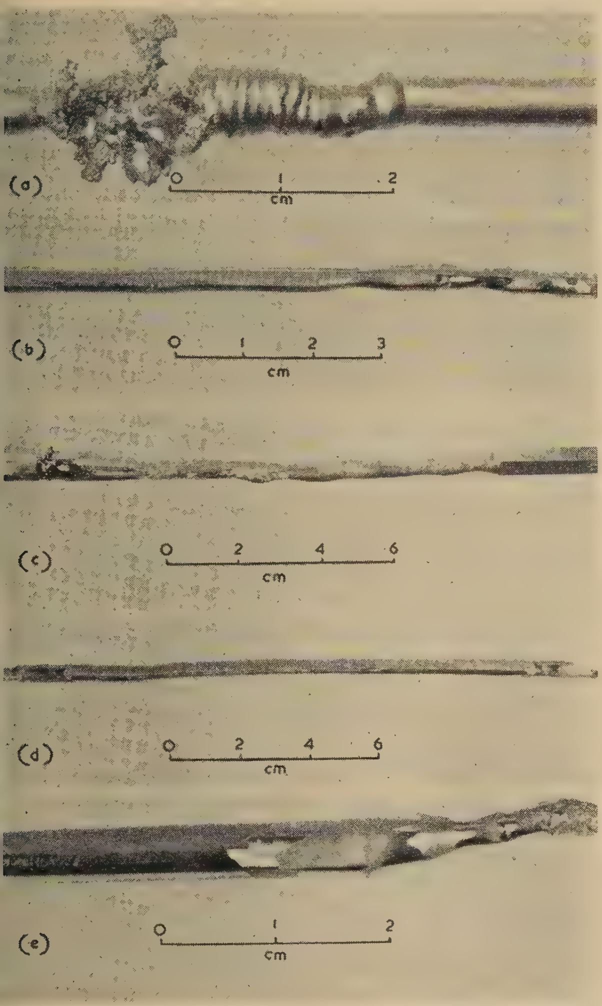
METHOD OF OPERATION

Mounting the specimen. To avoid kinking of the specime when it first melts, it is cut in half and mounted with the two halves in line and touching at the centre. The cathoc and focusing plates are then alined so that the specimen clears them throughout its length of travel. The electrode assembly is then placed in the bombardment chamber and the system evacuated. Before zoning the specimen the two halves must be joined; the abutting ends are therefore broug opposite the cathode. When the pressure is down to 10^{-5} mb, the h.t. is switched on to a pre-determined value. The cathode current is then gradually increased until the emission current is sufficient to make the specimen red hot. It is then moved slightly so that the upper half is hotter than the lower. As the emission current is further increased, a fused drop of material first appears on the upper half and quickly bridges the small gap between the two halves. The specimen is now ready for zoning.

Zoning a gas-free specimen. The traversing winch can only transmit a pull, hence specimens are zoned with the en zone travelling downwards. The specimen frame is ered until the starting point of the proposed length of el is opposite the cathode. This is usually about 2·5 cm the top V-block but depends on the melting temperature e specimen. The traversing gear is then mounted on the plate and coupled to the frame support rod. The h.t. is ched on and the emission current slowly increased until molten zone is established. The traverse is then initiated stopped when the molten zone is approximately 2·5 cm the lower V-block.

hereas with silicon the extent of the molten zone is clearly le, with most metals whose melting point is higher than of silicon (1420° C) the solid-liquid interface is not ernible (suggesting that the difference between the sivities of the liquid and the clean solid must be very ll) and the only indication of a molten zone is a noticeable ge of profile of the specimen. The value of the emission ent required to produce a molten zone is therefore ined by trial and error.

ning a gassy specimen. With most specimens, con- able outgassing occurs when the material first melts. This outgassing is quite violent and is sufficient to disrupt the specimen if too much of it is melted at one time. [Fig. 5(*a*) shows an extreme example of this.] The sudden surge in bombardment current which accompanies the outgassing causes the zone length to increase, become unstable, and collapse. Hand control of the emission current in these circumstances is impossible and to obtain specimens of near uniform diameter, an emission current controller is essential.



ig. 5. (*a*) The result of excessive outgassing on a nickel ecimen. (*b*) Tungsten single crystal. (*c*) Silicon single ystal seed grown along a polycrystalline rod. (*d*) henium single crystal. (*e*) Rhenium specimen showing e rapid change in size of grains from polycrystalline rod to a single crystal

The procedure for zone melting a gassy specimen is therefore as follows. The emission current is gradually increased and when the outer layer of the specimen becomes molten, the released gas carries out droplets of molten metal in a shower of sparks. The emission controller is then set at this value and a complete pass made at approximately 1 cm/min with the specimen "spitting" continuously. This is repeated with gradually increasing values of emission current on successive passes until no more spitting occurs. Once this state is reached, the specimen is completely outgassed and the molten zone extends right across the section. During these runs the grain size increases rapidly and the final product is usually single crystal. Zone refining at slow speeds can then be commenced.

During the outgassing of the specimen, small globules of it are ejected and caught on the cathode. Finally the cathode becomes heavily coated and fractures at a localized hot spot when the current is increased in order to maintain the emission. This is particularly so with tungsten and molybdenum specimens. For these metals, therefore, the filament may have to be changed two or three times before the specimen is completely outgassed.

Typical power requirements are 2 kV, 200 mA for 4·5 mm diameter tungsten, 1·5 kV, 80 mA for 6 mm diameter vanadium, 1 kV, 130 mA for 6·5 mm diameter iron.

Vapour pressure and visibility. The high vapour pressure of some metals at their melting point may be expected to interfere with the technique of electron bombardment because of arcing. The highest vapour pressure so far experienced has been that of iron (5×10^{-2} mb) and although this did not preclude the use of electron bombardment, considerable material was lost through evaporation.

The specimen is viewed through silica plates mounted in the nickel radiation shield. With some metals these plates quickly become coated with an opaque evaporated layer of metal once a molten zone is established. This is a disadvantage for specimens of non-uniform diameter which have to be viewed continuously in order to maintain a stable zone. In these cases, the process is stopped and the window replaced. For uniform specimens the zoning can be carried out with the appropriate setting on the emission controller and no disadvantage ensues from lack of visibility. As already mentioned, for most metals the length of the zone is not discernible and the only indication of melting is either a change of profile of the specimen, or the "spitting" when outgassing occurs. The latter phenomenon can be readily observed in the vacuum chamber even when the silica plates are blackened, and is therefore made use of for zoning the specimen without actually observing it.

The coatings on the silica windows can be analysed at different stages of the zone refining for an indication of the evaporation of impurities.

CONTAMINATION FROM THE TUNGSTEN CATHODE

Volatile impurities from the cathode can be avoided by running the cathode at a high temperature for about half an hour before mounting the specimen. The operating temperature of the cathode is approximately 2300° C and the vapour pressure of tungsten at this temperature is less than 10^{-6} mb. One would therefore expect little contamination from the tungsten; its possibility could be further reduced by operating at low emission and by siting the filament so that it subtends a small angle at the specimen. In some cases a filament of the same metal as that of the specimen itself may be used as a cathode. Spectrographic evidence of tungsten contamination has been observed in one specimen where high cathode temperatures were used.

RESULTS

Single crystals of tungsten, rhenium, tantalum, molybdenum, vanadium, nickel, silicon (using a seed crystal) and copper have been made. Their size was from 2 mm to 1 cm diameter and up to 16 cm long. Single crystals were not obtained in iron because of the phase change on cooling, nor in titanium.

FUTURE DESIGN CONSIDERATIONS

Some metals, e.g. titanium, zirconium, being highly reactive may require zoning in a vacuum of the order 10^{-6} mb or better. To obtain this, larger pumps and a larger bombardment chamber would be required. This would have to be constructed of metal. The tape cathode Fig. 2(*b*) is preferred, and consideration would be given to the design of a cathode system which sited the cathode so that globules from the outgassing specimen did not strike it. This would prolong the cathode life and would reduce contamination from it to a minimum.

For zoning very small diameter specimens, the cathode and focusing plate assembly would have to be more carefully designed. Provision could be made for the plates to be at a different potential from that of the cathode to allow finer focusing of the electron beam.

The choice between moving the cathode or the specimen depends mainly on workshop facilities. The moving cathode system has the advantage of greater specimen length for a given height of bombardment chamber, whereas the moving specimen system described is extremely simple in construction.

ACKNOWLEDGEMENTS

Discussion with J. F. Duke during the design and operation of the apparatus, and the useful experience gained by P. Rowcroft using the moving cathode apparatus is gratefully acknowledged.

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APPENDIX

Temperature distribution along the rod

Consider a semi-infinite cylindrical rod with the followin boundary conditions:

$$T = T_M \qquad \text{at } x = 0 \qquad \text{(1}$$

$$T = 0 \text{ and } dT/dx = 0 \qquad \text{at } x = \infty \qquad \text{(2}$$

where T is the surface temperature of the rod in degree Kelvin and x is the distance measured along the rod i centimetres. It is assumed that the temperature in the ro is a function of x only, and that the cylindrical surface the rod radiates according to Stefan's law with emissivity Any radiation incident on the rod is neglected.

Application of Stefan's law and the conservation of he to an element of rod dx gives:

$$d^2T/dx^2 = aT^4 \quad \text{where } a = 2\epsilon\sigma/KR \qquad \text{(3}$$

where R is the radius of the rod in centimetres, K is th conductivity in W cm^{-1} deg^{-1} and σ, Stefan's constant, taken as $5{\cdot}7 \times 10^{-12}$ W cm^{-2} deg^{-4}. With the bound conditions mentioned above, this may be integrated to

$$T^{-3/2} - T_m{}^{-3/2} = \alpha x \qquad \text{(4}$$

where

$$\alpha = (1{\cdot}8\epsilon\sigma/KR) = 10^{-5}\,(\epsilon/Kr) \qquad \text{(5}$$

where T_m is the melting point of the rod under considerati and r is the radius expressed in millimetres.

This may be written

$$f(T) - f(T_m) = x \qquad \text{(6}$$

where

$$f(T) = (\alpha T^{3/2})^{-1} \qquad \text{(7}$$

A plot of $f(T)$ against T then enables the temperature distr bution to be ascertained for any given value of T_m.

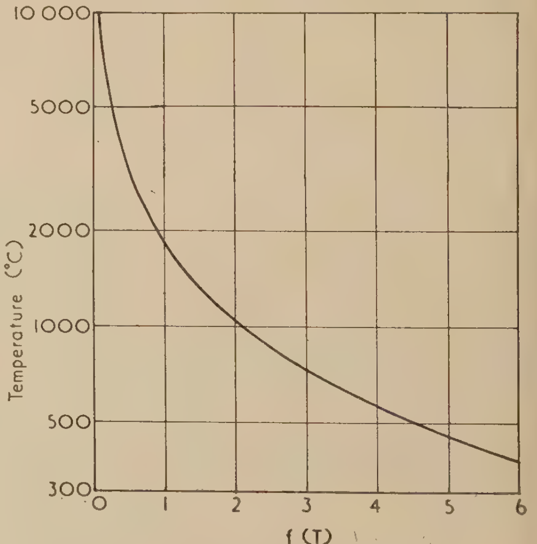

Fig. 6. $f(T) = 10^5\,T^{-3/2}$ (see text)

Multiply $f(T)$ by $\sqrt{(Kr/\varepsilon)}$ to obtain centimetres.
K = thermal conductivity in W cm^{-1} deg^{-1}.
r = radius in millimetres.
ε = emissivity.

n Fig. 6, $f(T)$ is plotted against T for $\alpha = 10^{-5}$, i.e. for etal where $\epsilon/Kr = 1$. Some typical values for K of cold als in W cm^{-1} deg^{-1} are: copper 4·2, iron 0·63, tungsten and tantalum 0·55. Emissivities of most metals lie ween 0·25 and unity at the high temperatures of interest. case plotted is therefore quite a realistic one, and gives ood idea of the type of temperature variation to be ected. To obtain x as a function of T when $\epsilon/Kr \neq 1$:

i) for a given T, measure $f(T) - f(T_m)$ from Fig. 6;
i) multiply this by $\sqrt{(Kr/\epsilon)}$ to obtain the corresponding value of x in centimetres.

idity of approximations

1) $dT/dx = 0$ and $T = 0$ at $x = \infty$. This is equivalent to ating the heat loss from the end of the rod to the heat v which would occur at that point if the rod extended efinitely. This amount of heat is in any case very small npared with the total incident on the rod.

2) The assumption that the rod does not receive radiation vell justified in practice since the radiation fluxes in the ion of interest, near the molten zone, are from 10^2 to 10^4 es greater than those existing at room temperature.

3) The problem is not strictly one-dimensional, and the face of the rod is somewhat cooler than the centre, for values of x. Any attempt to allow for this would be remely difficult, and it is supposed that its effect is only alter the temperature distribution of the rod in detail. A gh check on an actual rod during zone melting using an ical pyrometer showed a temperature distribution conent with that calculated using Fig. 6.

One can conclude that most of the heat incident on the molten surface is dissipated by radiation from the neighbourhood of the molten zone, and that the heat flow to the ends of the rod is slight in comparison. The very steep temperature gradient which undoubtedly exists at the solid-liquid interface may help to explain the comparative ease with which single crystals are produced. The exact form of the isotherms near the molten zone is of considerable practical interest, but is scarcely amenable to simple theoretical treatment. For the higher temperature metals, where the radiation losses are very high, one might anticipate that the isotherms are highly concave to the liquid zone (Fig. 7). Now the maximum diameter of rod which can be zoned is determined by the need to melt the centre of the rod without exceeding the critical zone length$^{(7,8)}$ for the metal. The highly concave solid-liquid interface would be advantageous in this respect, and might enable rods of diameter several times the critical zone length to be melted. This point clearly deserves experimental investigation.

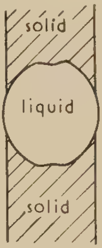

Fig. 7. General form of solid-liquid interface expected for high temperature metals

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Mercury-in-quartz thermometers for very high accuracy

By H. Moreau, Bureau International des Poids et Mesures, Sèvres, and J. A. Hall, A.R.C.S., B.Sc., F.Inst.P., and Vera M. Leaver, National Physical Laboratory, Teddington, Middlesex

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Experiments have shown that mercury thermometers of fused quartz do not show zero changes exceeding one or two hundredths of a degree after heating to 600° C, while heating for a month at 100° C did not produce a change greater than 0·001 deg C. Thermometers and observing equipment have been designed to take advantage of this stability, and observations on a thermometer ranged 0° to 28° C show a reproducibility of reading to within ±0·0007 deg C over a period of twelve months.

e liquid-in-glass thermometer is such a simple and con-ient instrument that it is worth while to study any means increasing its sphere of usefulness. Improvements may be de both by extending the working temperature range d by increasing accuracy within the present range. The sent paper is chiefly concerned with the second of these jects.

When mercury is used as the operating fluid, the tempera-e range lies between the freezing point of mercury 38·87° C) and about 600° C, above which temperature the ssure required to prevent the mercury column from eaking up becomes excessive (greater than 30 atm). The e of the eutectic alloy of mercury and thallium enables the nge to be extended downwards to about −55° C, but the per limit of 600° C cannot be passed, whatever the liquid ing, if glass is used as the envelope.

The use of glass also sets a limit to the accuracy which n be obtained within the working range, since the volume of a glass bulb not only shows a progressive change with time (secular change) but does not return at once to its original volume after exposure to a higher temperature. In a thermometer, this results in a temporary depression of zero which gradually diminishes until recovery is complete, a process which usually takes several days. A glass thermometer must always be used in a systematic manner to take account of these zero changes, and, if the highest accuracy is to be obtained, the zero must be observed after each temperature reading. Apart from its inconvenience, this is not a very easy operation, since the zero begins to recover from its temporary depression immediately it is removed from the higher temperature,$^{(1)}$ and even at room temperature, where conditions are most favourable, zero instability limits the accuracy to about ±0·002 deg C. An alternative, but less accurate, method is to calibrate a thermometer in terms of its zero as measured after it has been held for two days or more at a standard low temperature (preferably 0° C).

EARLY ATTEMPTS TO REPLACE GLASS AS BULB MATERIAL

In spite of these difficulties, mercury thermometers are widely used in accurate work, since they avoid the need for the somewhat costly apparatus required for resistance thermometry. The Bureau International des Poids et Mesures (B.I.P.M.) has used accurate mercury thermometers for fundamental standardization work for the past seventy years, and an investigation into improved types was started some twenty years ago in the hope that the use of a different material for the bulb might lead to an improvement in accuracy. As long ago as 1895, L. Marchis(2) attempted to supersede glass by joining a platinum bulb on to a stem of *verre vert* (soda glass) and this method was tried again at the B.I.P.M., but was abandoned on account of constructional difficulties and the fragility of a thermometer of this type. Attention was then directed to the use of fused quartz. The first attempts to use this material seem to have been made by A. Dufour(3) who pointed out that quartz might have advantages both for extending the temperature range upwards and for improving the accuracy, as the zero would probably be more stable. Quartz also has the advantage of having an expansion coefficient ten or fifteen times less than those of the usual thermometer glasses, and it shows a significant advantage over glass in resistance to attack by both acids and alkalis, though it suffers to some extent in boiling alkaline solutions.

Dufour's work was chiefly concerned with the upward extension of the range, which he studied with a thermometer filled with tin and scaled from 240° C to 580° C. Since that date, work has mostly been devoted to high temperatures, and quartz thermometers filled with gallium have been used up to 1000° C, but not for any great accuracy. They are normally of the enclosed-scale type, with a thin-walled capillary tube and a separate scale on translucent quartz enclosed in a protecting tube. This form of construction is not, however, suitable for the highly accurate thermometers required by the B.I.P.M.

THE DESIGN OF ACCURATE MERCURY THERMOMETERS

Even if perfect stability of zero were achieved, accuracy would still be limited by irregularity of movement of the mercury meniscus. This increases as the bore of the capillary is made finer, and there is always the temptation to use a fine capillary in order to increase sensitivity. Ch.-Ed. Guillaume pointed out in 1889 (Ref. 4, p. 179–181) that there is nothing to be gained by increasing the length of the degree beyond about 1 cm, and this is undoubtedly true provided that full precautions are taken to eliminate parallax errors and that the observer is capable of estimating the subdivision of the graduation interval (0·1 deg C) to one part in fifty with the virtual certainty of being correct to one in twenty (i.e. 0·005 deg C). If the thermometer has sufficiently fine graduation lines (thickness of the order of 1/20 of the spacing) this accuracy is obtainable by a good observer with long experience. On the mean of a series of readings, the temperature should then be located to within ±0·002 deg C. Experience has shown that this accuracy is, in fact, more readily attainable with the thermometers made by Tonnelot, and from 1898 onwards by Baudin, for the B.I.P.M., and divided to 0·1 deg C (1 deg = about 7 mm) than with modern open-scale thermometers divided to 0·01 deg C (1 deg = about 60 mm). These latter thermometers are normally made with oval bores measuring about 70 × 50 μ, but if "jumping" is to be kept below 0·002 deg C without the need for continual tapping of the thermometer, a bore of about 120 μ diamete or minor axis is necessary. If quartz is used, a sensitivity o 7 mm/deg C is given by a bulb of about 0·45 cm^3, which can conveniently be made with an external diameter of less than 6 mm. Three disadvantages follow any attempt t increase sensitivity by increasing the diameter: (i) thermal lag is increased; (ii) for a given wall thickness, the effect o changes in pressure on the bulb increases approximatel proportionately to the diameter (Ref. 4, p. 110) and, (iii) risk of parallax error is increased as it is not desirable to reduce the stem diameter below that of the bulb.

With a thermometer of this type it is necessary to locat the meniscus relative to the scale to within 7 μ for an accurac of 0·001 deg C, and it is therefore desirable to have the scal directly engraved on the capillary; that is, the thermomete should be of the solid-stem type. Consequently, the tubin for the stems should have a diameter of 5 or 6 mm with regular bore of diameter about 120 or 150 μ, while tubi for the bulbs should be about the same diameter, with a wal thickness of from 0·5 to 0·6 mm.

It is much easier to make a thin-walled capillary in quar than one having an outside diameter of about 5 mm; th difficulties of manufacture arise not only from the hi melting point of the quartz, but especially from the high rat of external to internal diameter and from the low toleran laid down for variations in cross-section of the bore, whic should be uniform to better than ±1% if possible.

RECENT EXPERIENCE WITH FUSED QUARTZ

With all these considerations in mind, the B.I.P.M. ha for many years proposed to arrange for the manufacture a thorough test of all-quartz thermometers of high precisio Attempts to obtain suitable tubing have been made sinc

Table 1. *Stability of zero of thermometers*

Date	*Heat treatment*	*Zero reading after heat treatment*
	Thermometer S.K. (fused quartz)	
August 1936	Room temperature (19° C)	+0·031° C
	A few minutes at 100° C	+0·030° C
January 1937	1 month at 100° C	+0·031° C
February 1937	Room temperature (17° C)	+0·033° C
	1 h at about −35° C	+0·032° C
	18 h at 130° C	+0·031° C
April 1937	6 h at −35° C	+0·028° C
August 1937	Room temperature (21° C)	+0·028° C
February 1938	Room temperature (19° C)	+0·028° C
April 1941	Room temperature (12° C)	+0·028° C
January 1945	Room temperature (12° C)	+0·030° C
September 1948	Room temperature (17° C)	+0·027° C
March 1952	Room temperature (18° C)	+0·027° C
December 1955	Room temperature (21° C)	+0·027° C
October 1956	Room temperature (19° C)	+0·027° C
	*Thermometer 254 (fused quartz)**	
April 1941	Room temperature (12° C)	+0·049° C
	2 h 15 min at 200° C	+0·052° C
	15 h at 300° C	+0·061° C
	5 h at 14° C	+0·059° C
	5 min at 375° C	+0·044° C

* The distillation of mercury and break-up of the column which occurred in this vacuous thermometer limit the accuracy obtainable to 0·01 deg C.

5 (with some interruption on account of the war), but it . not until 1949–50 that any acceptable samples were ained. However, sufficient tubing had been obtained to e two experimental thermometers, of which the zero ility proved to be almost perfect (Table 1).

nfortunately, persistent difficulties of manufacture were ountered both in France and in other countries, so an rmediate solution was sought by trying to combine the antages of fused quartz for the bulbs with those of the al glasses for the stems. The attempts to join a fused-rtz bulb to a stem of *verre vert* through a graded joint e abandoned, as the graded joint was both fragile and cult to make. In 1948 an investigation into the Corning s Vycor was started. This glass contains 96% silicon xide, and its properties are very similar to those of fused rtz. The thermometer stems submitted by the glass kers were very satisfactory, both optically and for larity of the bore, but the diameter of the bore was too e (0·4 mm) for the type of thermometer which was in d, necessitating an excessively large bulb to give the mal length of degree. The manufacture of tubes with r bores was not brought to a satisfactory conclusion, ugh it was not considered to be impossible. Nevertheless, three experimental thermometers were constructed, one entirely in Vycor and two with bulbs of fused quartz joined on to Vycor stems. These thermometers (in particular those of quartz-Vycor) appeared to have as satisfactory a stability of zero as those made entirely of fused quartz (see Table 2).

Table 2. *Stability of zero of thermometers*

Date	*Heat treatment*	*Zero reading after heat treatment*
	Quartz bulb, Vycor stem	
	Experimental thermometer divided to 0·2 deg C (1 deg C = 3·4 mm)	
	Accuracy of observations: ±0·005 deg C	
ptember 1948	Room temperature (17° C)	+0·040° C
bruary 1949	30 min at 100° C	+0·039° C
rch 1949	185 h at 0° C	+0·035° C
	5 min at 100° C	+0·034° C
rch 1952	Room temperature (18° C)	+0·034° C
cember 1955	Room temperature (21° C)	+0·034° C
tober 1956	Room temperature (19° C)	+0·034° C
	Quartz bulb, Vycor stem	
	Experimental thermometer divided to 1 deg C (1 deg C = 0·9 mm)	
	Accuracy of observations about 0·02 deg C	
ptember 1951	Room temperature (18° C)	+0·07° C
	30 min at 300° C	+0·07° C
	17 h at 18° C	+0·08° C
	4 h 15 min at 300° C	+0·09° C
	1 h 45 min at 500° C	+0·09° C
	18 h at 500° C	+0·08° C
tober 1951	1 month at 0° C	+0·06° C
	5 h at 600° C	+0·04° C
cember 1955	Room temperature (21° C)	+0·05° C
	Vycor bulb and stem	
	Experimental thermometer divided to 0·2 deg C (1 deg C = 3·5 mm)	
	Accuracy of observations: ±0·005 deg C	
ptember 1948	Room temperature (17° C)	−0·067° C
bruary 1949	30 min at 100° C	−0·065° C
arch 1949	185 h at 0° C	−0·071° C
	5 min at 100° C	−0·067° C
arch 1952	Room temperature (18° C)	−0·067° C
cember 1955	Room temperature (21° C)	−0·070° C

In 1949–50, the firm of Quartz et Silice, in France, took up the manufacture of thermometer stems in fused quartz, and delivered to the B.I.P.M. a batch of tubes which, after selection, could be used for the manufacture of precision mercury thermometers. The raw material for the manufacture of this fused quartz consists of chippings from quartz crystals, selected so as to avoid natural faces which would risk the introduction of impurities which could not be eliminated subsequently. The crystals are ground to a fine powder which is then treated by acids to remove residual impurities and then melted electrically *in vacuo* at about 1700° C. This fusion yields a transparent material (99·97% silicon dioxide) which is re-melted and worked into the desired form.

The capillary tubes have been made in a specially-designed machine by a process of drawing accompanied by additions of quartz until the desired ratio between the internal and external diameters is obtained. On the whole, this first batch of tubes was satisfactory in quality; a few bubbles and striations remained in the body of the quartz, but (and this is the important point) the cross-section of the bore did not show any sharp discontinuities.

The manufacture of six mercury-in-fused-quartz thermometers from these capillaries was entrusted to the firm of Prolabo, in Paris. The thermometers were evenly divided to 0·1 deg C, and the length of 1 deg C varied from 5·5 mm to 8·5 mm according to the range of the thermometer.

The normal method of avoiding parallax with transparent standard thermometers is to take duplicate readings with the graduations both in front of and behind the capillary. In order to avoid the necessity for this, the new thermometers have been made with two sets of graduations diametrically opposed on the stem; parallax can then be avoided by bringing the two graduations adjacent to the reading into coincidence. This method seemed preferable to the alternatives which suggested themselves, such as the provision of a reflecting back to the stem or the grinding of a flat on it so that the graduations could be brought within a few tenths of a millimetre of the capillary. The graduation lines (about 25 μ in width) are made with a dividing engine (Société Genevoise d'Instruments de Physique) using a diamond tool operating directly on the quartz, the chemical properties of fused quartz making it impossible to obtain suitable graduation lines by the use of hydrofluoric acid.

CALIBRATION AND PERFORMANCE OF THE THERMOMETERS

Measurements at the Bureau International des Poids et Mesures. Calibration of the thermometers was first carried out at the B.I.P.M. by the classical methods (calibration of the bore, measurement of fundamental interval, pressure coefficients, etc.) so as to give temperature readings on the "mercury-in-fused-quartz" scale. This arbitrary scale, on which the differential expansion of mercury and quartz would be a linear function of temperature, differs from the International Temperature Scale: if a thermometer is adjusted to read correctly at 0° C and 100° C, the difference in the neighbourhood of 50° C should be of the order of 0·1 deg C, but the exact value is uncertain on account of discrepancies between the various published values for the expansion coefficients. When sufficient of the new thermometers have been examined, further light will be thrown on this matter, but in the present paper we shall confine ourselves to the question of reproducibility of reading of a typical thermometer (No. 328) in the range 0° C to 28° C. If the thermometer has zero corrections at these two temperatures, the maximum departure from the international scale between them will only be of the order of 0·003 deg C.

The calibration of the bore of this thermometer (0–28° C) was carried out at each degree (=8·5 mm) in the following manner: two independent single calibrations in four parts by the Hansen–Pérard method⁽⁵⁾ were used to establish the corrections for variations in cross-section of the bore at the quarter-lengths of the scale, and the results given in Table 3 were obtained. Each of these quarters was then divided into seven parts by means of simultaneous (or crossed) calibrations by the Neumann–Guillaume method,⁽⁶⁾ the results being adjusted to the system having zero corrections at 0° C and 28° C. The calibration errors at 7, 14 and 21° C do not appear to exceed ±0·002 deg C, while at the intermediate points, where we have to take account of the errors introduced by the simultaneous calibrations, the uncertainty probably does not exceed three or four thousandths of a degree.

Table 3. *Thermometer* 328 (*calibration of bore in quarters*)

Scale reading	*Correction (deg C)* *1st calibration*	 *2nd calibration*
0	0	0
7	−0·0391	−0·0358
14	−0·0150	−0·0130
21	+0·0435	+0·0406
28	0	0

The calibration curve of the bore of the thermometer is shown in Fig. 1, and it will be seen that the maximum slope is about 1·5%. It can be shown (Ref. 4, p. 47) that the slope at any point is equal to the percentage departure of the cross-section of the bore at that point from the mean cross-section over the length of scale which is adjusted to read correctly at the ends. Fig. 1 also shows the calibration curves of the bores of some representative thermometer stems of similar type made of glass: the quartz tube does not suffer seriously from the comparison.

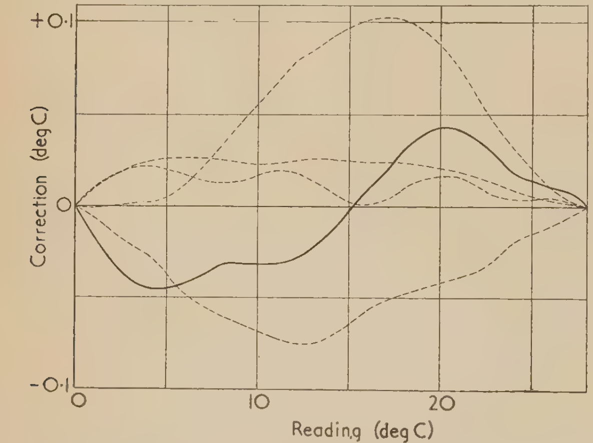

Fig. 1. Calibration curves of the bores of quartz and glass thermometer stems. Full line, quartz (No. 328). Broken lines, glass

Measurements at the National Physical Laboratory. The regularity of the dividing was examined with the results shown in Fig. 2. The upper curve gives the errors in position of the graduations of the front scale, the mean error of the two scales being taken as zero at 0° C and 28° C. The lower curve gives the displacement of the graduations of the back scale relative to the front scale, the zero lines having been brought into coincidence. Neither curve shows errors appreciably in excess of 0·001 deg C.

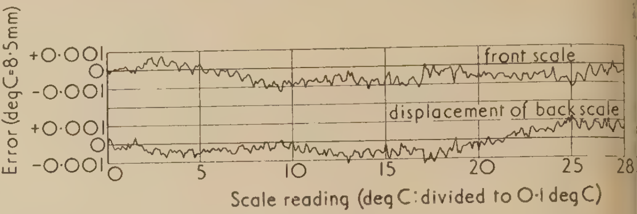

Fig. 2. Errors of graduation of thermometer scales

The thermometer was then compared with platinum resistance thermometers in the water-bath shown diagrammatically in Fig. 3. This consists of two vertical cylindrical chambers, connected at top and bottom. Heat can be applied at the bottom of the left-hand chamber, in which the water is lifted by a propeller of about 10 cm pitch working at 700 rev/min. The water flows in a turbulent manner into the working space on the right and completes the circuit at the bottom. Experiments have shown that the temperature throughout the working space is uniform to within ±0·001 deg C at temperatures up to 50° C. In the present work the bulbs of two resistance thermometers and the mercury thermometer have been kept at the same level and within a circle of 6 cm diameter. The bath is lagged with granulated cork, and, in order to be able to maintain a very slowly rising temperature at temperatures below atmospheric, provision is made for circulating iced water through the bath. Water is pumped from the ice tank and the flow is regulated by a special valve⁽⁷⁾ in a lagged pipe which feeds it into a funnel and thence into the bath just above the propeller so that it may be thoroughly mixed with the water circulating in the bath. The normal overflow of the bath is diverted

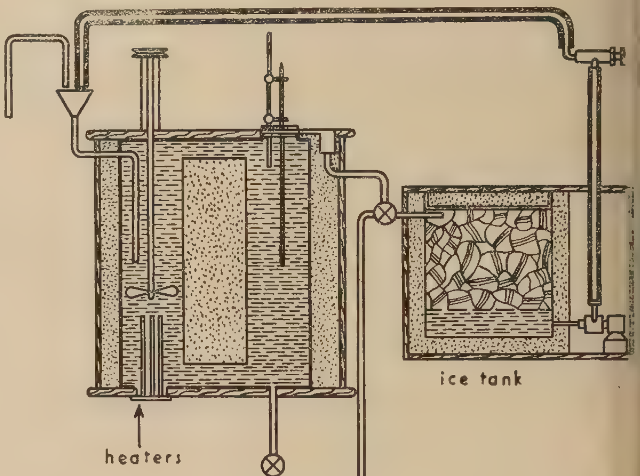

Fig. 3. Water bath used for comparison with platinum resistance thermometers

the top of the ice-tank. For the sake of clarity, the ice-
k has been displaced in Fig. 3: in fact, the lagged pipe is
t as short as possible.

n order to get the best regularity of movement of the
iiscus in a mercury thermometer, it is desirable to work
n a slowly rising temperature, and readings are normally
le by visual estimation between the graduation lines.
ce this method limits the accuracy to about ±0·002° C,
have adopted an arrangement by which the moving
iiscus can be followed with a micrometer eyepiece. This
uires that the relative vertical positions of the thermo-
er and the observing telescope shall not change by more
n about 2 μ (equivalent to about 0·0003 deg C) during a
of readings, and this has been satisfactorily achieved.

he thermometer is held by springs in two V-grooves
nped one above the other on an Invar rod (Figs. 4 and 5).

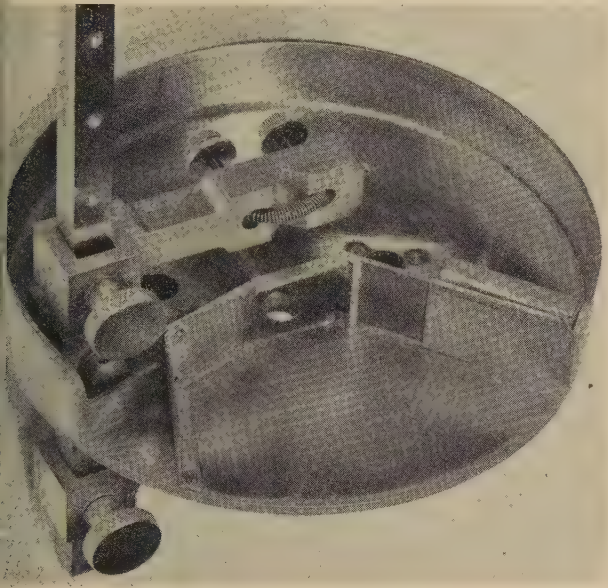

Fig. 4. Thermometer holder

ey may be fixed either above or below the water-level,
cording to the part of the thermometer under observation.
g. 4 shows one spring above and one below: in Fig. 5
th are above. The plate carrying the rod is clamped to the
p of the bath, a thin rubber gasket being used to make a
ter-tight seal. The water level in the bath is maintained
that of the weir seen on the left in Fig. 4, and the thermo-
eter is observed through a small window. At low tempera-
res it is necessary to wipe this from time to time to remove
ndensation, and this can be done without risk of moving
e thermometer. The observing telescope is mounted on a
angular frame of channel section bolted to the bath. The
escope is adjustable for height by a series of pairs of
stance pieces, and it is pivoted at the objective so that it
n be tilted or rotated horizontally by means of fine screws
ar the eye-piece. In order that parallax should not exceed
0005° C over a range of 0·1 deg C, the working distance
s made 30–32 cm, and, so as to shorten the telescope in
e interest of rigidity, a reduction of about 3 : 2 by the
jective has been accepted. The objective consists of two
escope objectives of 32 cm and 22 cm focus and 2 cm
ameter placed back to back, so that each is working in its
rmal "infinity" position, and between them is a mercury-
een filter and an iris diaphragm. The use of the green filter has been found to reduce fatigue, and the iris diaphragm enables the observer to choose the preferred compromise between depth of field (necessary with the double divisions) and brightness of image. The thermometer is illuminated from behind by means of a Perspex light guide, the matted end of which has the same width as the stem of the thermometer.

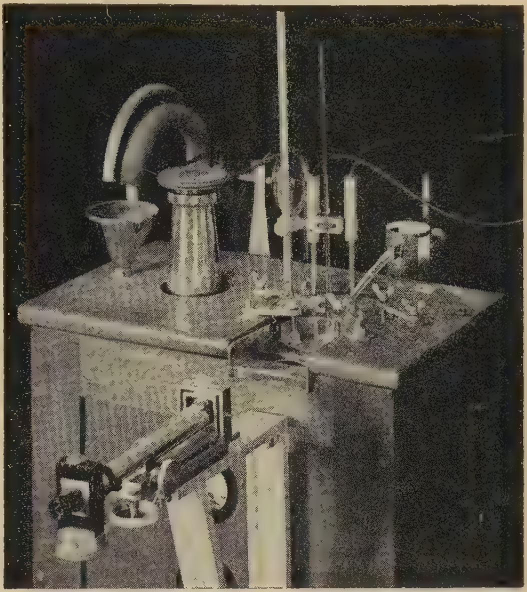

Fig. 5. Arrangement of bath and observing telescope

The appearance of the field through the telescope is shown in Fig. 6, which has been drawn to scale so as to show the departure from coincidence of neighbouring graduation lines. No difficulty has been experienced in obtaining unambiguous coincidences and by comparing the departures on opposite sides of the sighting point, it is possible to locate the latter to within half the space between successive graduations.

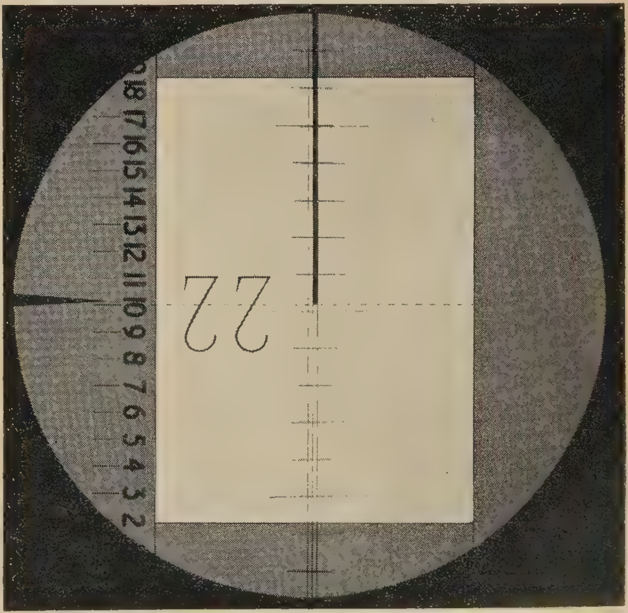

Fig. 6. Field of view of telescope

(Alternatively, it is possible to maintain coincidence and eliminate parallax over the whole field by placing a small diaphragm at the principal focus of the objective so as to produce a telecentric system, in which the entrance pupil is at infinity.(8)) An interrupted cross-wire has been chosen in preference to the normal double cross-wire. The latter is admirable for setting the graduation lines, where the field is symmetrical, but it is very doubtful whether an observer would make a corresponding setting on the boundary between bright and dark, as at the mercury meniscus. The lateral movement of the telescope makes it possible to locate the meniscus just within one of the gaps in the cross-wire. The screw of the eyepiece (made to an N.P.L. design by the Precision Tool and Instrument Co.) has a pitch of 0·5 mm, so that each graduation on the micrometer head corresponds to a little less than 0·001 deg C, and settings can be made by estimation to about 0·0002 deg C.

The observational procedure is as follows. Four settings (moving in the direction of a rising reading) are first made on each of the graduations adjacent to the meniscus, the normal spread of the settings not exceeding 0·001 deg C. Twelve simultaneous observations are then made against a platinum resistance thermometer at intervals of about 12 s and then the readings on the graduation lines are repeated. A similar set of readings is taken against another platinum thermometer, and a final observation on the graduations is made. If the three sets of readings on the graduation lines do not agree to within 0·001 deg C, the observation is not used.

Resistance thermometer readings are taken on a Smith bridge (Type III).(9,10) The readings are taken on signals given by automatically operated buzzers, and each observer has a microphone with which the readings are recorded on a single tape recorder. A typical set of observations is shown in Fig. 7 and Table 4.

In Fig. 7 mean straight lines have been drawn through the observed points, with broken lines to show departures of ±0·001 deg C. Except for the first setting of Observation 90 no mercury thermometer reading lies more than 0·0007 deg C off the mean line, and, though the bridge can be set to 0·0001 deg C, its readings are only slightly better than those of the mercury thermometer, owing to the greater ease of rapid setting with a micrometer as compared with keeping a galvanometer in balance.

Table 4. *Typical set of observations*

	Mercury-in-quartz thermometer 328 *Graduations* 18·9	19·0				*Resistance thermometer Q. 8*	*Mercury minus resistance deg C*
	12·029	13·409					
	12·029	13·420					
	12·026	13·429					
	12·026	13·420					
	12·028	13·420					
Obs. 90			0 *s*		5½ *s*		
			Micrometer	12·233*	Bridge	2–7–8–5–1–2–4*	
			Thermometer	18·9151	Resistance	27·853 26	
			Thermometer (corrected)	18·8775	Temperature	18·883 3	—0·0058
			100 *s*		105½ *s*		
			Micrometer	12·380*	Bridge	2–7–8–5–2–3–2*	
			Thermometer	18·9256	Resistance	27·854 34	
			Thermometer (corrected)	18·8880	Temperature	18·893 8	—0·0058
	12·016	13·410					
	12·019	13·417					
	12·023	13·412				*Q.* 10	
	12·019	13·408					
	12·019	13·412					
Obs. 91			0 *s*		6½ *s*		
			Micrometer	12·890*	Bridge	2–7–7–7–1–1–4*	
			Thermometer	18·9623	Resistance	27·773 09	
			Thermometer (corrected)	18·9251	Temperature	18·930 8	—0·0057
			100 *s*		106½ *s*		
			Micrometer	13·043*	Bridge	2–7–7–7–2–3–5*	
			Thermometer	18·9733	Resistance	27·774 30	
			Thermometer (corrected)	18·9361	Temperature	18·942 7	—0·0066
	12·029	13·410					
	12·020	13·412					
	12·017	13·415					
	12·020	13·413					
	12·022	13·412					
	12·023	13·415 Mean					

* Values taken from the mean curves of Fig. 7.

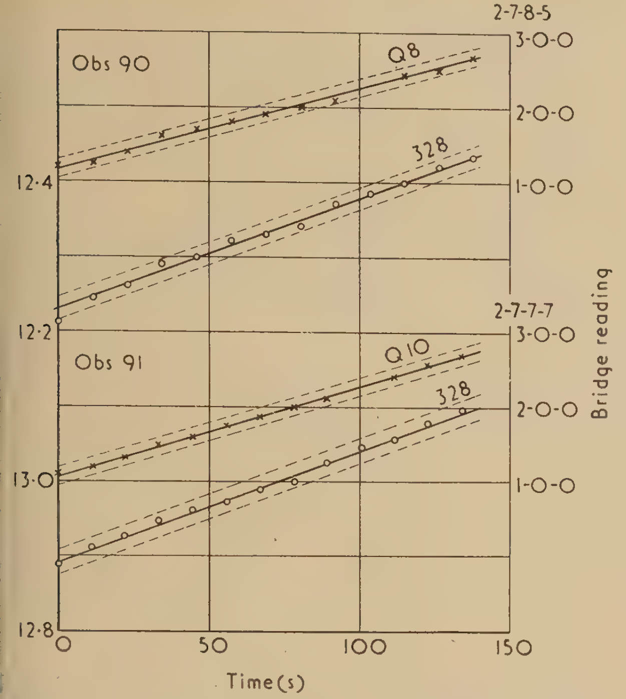

Fig. 7. Mercury and resistance thermometer readings

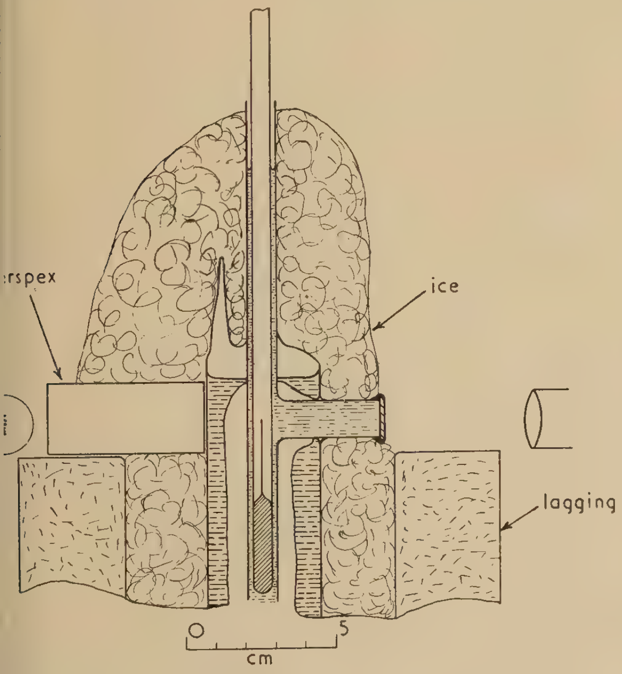

Fig. 8. Triple point of water cell for use with mercury thermometers

The lag constant of the mercury-in-quartz thermometer is found to be about 1·5 s, and the values for the resistance ermometers *Q*. 8 and *Q*. 10 were 7 s and 8 s respectively. esistance thermometer readings are therefore taken from curves 5½ or 6½ s after the corresponding mercury thermo- ter reading.

Zero readings were taken at the triple point of water 0100° C) in a modified form of the cell described by Barber, Handley and Herington(11) as Type *Z*. The normal type of cell is not suitable for mercury thermometers as at least 10 cm of the stem are invisible if the bulb is adequately immersed. In the modified form, a side-tube is joined to the thermometer tube just below the level of the water in the outer tube (see Fig. 8). This side-tube is closed with a plane window (fixed in position with wax) so that accurate observations can be made with as little as 40 mm between the top of the thermometer bulb and the zero graduation. Viewing and illuminating conditions were closely similar to those used in the water bath. The thermometer was held in a rubber bung bored so as to fit on the top of the thermometer tube, and a side-tube was provided so that the external pressure on the thermometer could be momentarily reduced. In this way, readings could be taken when the meniscus had just risen to the reading and after the thermometer had been lightly tapped. Experiments in the water bath had shown that there was a fairly consistent difference of about 0·005 deg C between readings taken on a rising and on a falling reading. The values obtained from rising readings were independent of the rate of rise. The difference between rising and falling readings could, of course, be minimized by the use of a somewhat wider bore for the capillary. The reproducibility of readings at the triple point was within ±0·0007 deg C.

The comparison with the platinum resistance thermometer extended over a period of twelve months, and four different resistance thermometers were used. The calibration and pressure corrections obtained from the B.I.P.M. observations were applied, and zero and "fundamental interval" corrections from the N.P.L. observations were then made to reduce the errors to zero at 0° C and 28° C. In order to check the stability of zero of the thermometer, observations were repeatedly made at 24° C (the temperature at which the stirred bath normally comes into equilibrium) and these all lie within a range of 0·0015 deg C. All the results of the comparison with resistance thermometers have been plotted in Fig. 9 and the shaded zone indicates the region in which the corrections might be expected to lie, having regard to different workers' values for the expansion coefficients of fused quartz and mercury. At the temperatures of 7, 14 and 21° C (where the calibration of the bore is least subject to error) the mean curve passes very close to the shaded zone.

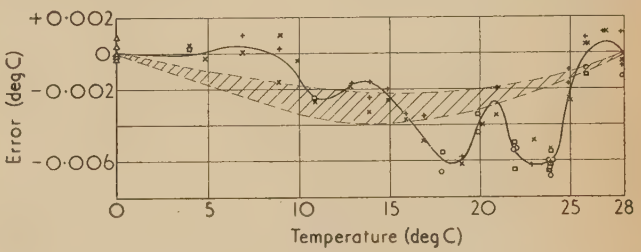

Fig. 9. Correction curve of thermometer 328 to International Temperature Scale

○ *R*.8 }
□ *R*.12 } resistance thermometers.
+ *Q*.8 }
× *Q*.10
△ triple point.

CONCLUSIONS

Observations carried out over twenty years have confirmed that within the limit of accuracy of the thermometers (a few thousandths of a degree Celsius under the best conditions) there are no changes in the zeros of mercury-in-quartz thermometers either with time or after exposure to moderately high temperatures (200° C to 300° C). At higher temperatures (up to 600° C) the small variations observed are not systematic and arise largely from the experimental conditions. In any case, the variations are of the same order as the accuracy with which such temperatures can be determined.

In the range 0° C to 100° C a calibration can be established at any point to $\pm 0{\cdot}001$ deg C by comparison with standard platinum resistance thermometers and the calibration so obtained should remain good indefinitely. This technique appears to be less laborious (and possibly somewhat more accurate) than the classical method of calibration involving determination of the variations of cross-section of the bore; this last method is, however, the only one to use when it is intended to determine the corrections to reduce the mercury-in-quartz scale to the International Temperature Scale.

The limiting factor on the accuracy is imposed by slight irregularity in the movement of the mercury meniscus and by the accuracy with which the position of the meniscus between the divisions can be estimated. The first of these errors is so small that special means to reduce the second are justified (e.g. following the meniscus with a micrometer eyepiece). In this way an accuracy at least twice as great as that given by the most precise mercury-in-glass thermometers can be obtained. For the measurement of temperatures in the range 0° C to 100° C to an accuracy of $\pm 0{\cdot}001$ deg C, therefore, the use of a mercury-in-quartz thermometer with a rigidly mounted observing telescope offers an alternative to a platinum resistance thermometer with elaborate and expensive measuring equipment.

The results so far obtained are thus very encouraging, but improvements are still necessary. In France, manufacture of quartz tubing has not yet passed the experimental stage, and it is to be hoped that research on the problems involved will be continued by the firms which specialize in the manufacture and working of fused quartz, as has recently been done by the Thermal Syndicate in England. If the difficulties which still remain cannot in the end be overcome, the use of a quartz bulb with a Vycor stem remains a possibility which would be worth investigating. The general use of mercury-in-quartz thermometers now depends on the possibility of regular commercial manufacture of the necessary tubing.

ACKNOWLEDGEMENTS

We wish to thank Monsieur J. C. Georges, Technical Director of Quartz et Silice and Monsieur G. Veyrun, Works Director of Prolabo, for the interest they have shown in the manufacture of the thermometer stems and the completed thermometers. We also thank Monsieur G. Girard, of the Bureau International des Poids et Mesures, who helped with the calibration observations on the thermometers. The comparison with the platinum resistance thermometers was carried out as part of the research programme of the National Physical Laboratory, and is published by permission of the Director of the Laboratory.

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The measurement of the momenta of high energy charged particles in a diffusion cloud chamber

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The problems associated with the measurement of the momenta of high energy nuclear particles in a diffusion cloud chamber are described. An optical system has been developed for which the apparent curvatures in the object due to distortion have an average value of $0{\cdot}005\ \mathrm{m}^{-1}$ over the field of view. Spurious track curvatures due to convective gas motions within the cloud chamber are of similar magnitude, when a flash delay time adequate to allow the photography of the tracks of minimally ionizing particles in hydrogen is used. These figures result in a nominal accuracy of about 2% in the momentum of a 1000 MeV proton (momentum $1{\cdot}7 \times 10^9$ eV/c) in a magnetic field of $1{\cdot}3 \times 10^4$ G for tracks 20 cm long. The corresponding maximum detectable momentum is $8{\cdot}5 \times 10^{10}$ eV/c.

INTRODUCTION

A high pressure diffusion cloud chamber$^{(1)}$ has been designed for use with the Birmingham 1000 MeV proton synchrotron.$^{(2)}$ To date the chamber has been operated with fillings of hydrogen$^{(3)}$ and deuterium$^{(4)}$ for the study of nucleon-nucleon interactions at energies at which the production of π-mesons is important. The analysis of interactions occurring within the chamber by the methods of relativistic dynamics is made possible by a knowledge of the momenta of the interacting particles. The cloud chamber is therefore operated in a pulsed magnetic field of peak value $1{\cdot}3 \times 10^4$ G.

The accuracy with which the momentum of a particular particle can be measured is limited by sources of error in the apparatus and by the measuring technique. The problem is essentially that of measuring accurately the spatial curvature of the trajectory of the particle. A 1000 MeV proton has a momentum of $1{\cdot}7 \times 10^9$ eV/c and the radius of curvature of its trajectory perpendicular to a magnetic field of $1{\cdot}3 \times 10^4$ G is about $4{\cdot}3$ m. For a track of length 20 cm the sagitta is $0{\cdot}11$ cm so that, if the error in curvature is not to exceed 2%, the sagitta must be known to about 20 μ. Particles of lower momenta produced in interactions 'e trajectories of greater curvature but such particles often erge at large angles to the horizontal direction of the mary particles. They therefore appear as relatively short cks in the rather shallow sensitive volume of the diffusion ud chamber.

'or long tracks the accuracy of curvature measurement is ited by the convective gas motions which occur within chamber during the interval between the entry of the ticles and the instant of photography. It is therefore 'antageous to minimize this time. In the case of short cks the accuracy of curvature measurement is limited by precision of the measuring technique used to determine sagittae. The most accurate method of curvature deter-iation is to calculate the curvature from co-ordinate asurements made on the photographs using a low power roscope.(5) For current experiments with the diffusion mber it may be shown(6) that errors in momentum asurements due to multiple coulomb scattering are ligible. Important geometrical corrections(7) must be lied when curvature measurements are made on the tographs of tracks at large angles to the horizontal. The tial variation of the magnetic field must also be known. e oxygen content of the chamber gas must be reduced to ery low value ($<0{\cdot}01\%$) to limit the gas motion due to paramagnetic susceptibility when a pulsed magnetic field ised.

This paper is concerned with an investigation of the cision of the optical systems and of the spurious curvatures m other sources in the Birmingham chamber.

THE OPTICAL SYSTEM

The optical system now in use is shown in Fig. 1. The iical aperture in the magnet yoke allows photography of sensitive volume with minimum obstruction of the flux urn path. The conical upper portion of the chamber ovides a reservoir of vapour which ensures uniform fusion over the diameter of the sensitive volume, and also owed the use of a single 9 in. diameter disk of armour-plate ss to seal the top of the chamber in the original design. is disk has been replaced by two plate glass disks $2\frac{1}{4}$ in. in diameter by $\frac{1}{2}$ in. thick mounted in a stainless steel plate for reasons which will be discussed below. The 17 in. diameter by $2\frac{1}{2}$ in. deep sensitive volume of the chamber is illuminated through windows of $\frac{7}{8}$ in. thick armour-plate glass by a flash tube on each side of the chamber. The light from each tube is collimated by a cylindrical lens; this has been found to give much better collimation with little decrease in intensity, compared with the wide aperture parabolic mirrors originally used. An improved track to background contrast and shorter flash delay time have thus been achieved.

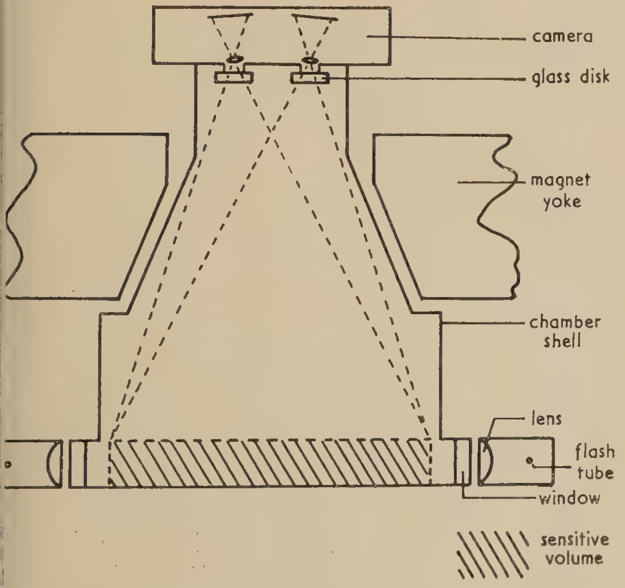

Fig. 1. The optical system

Stereoscopic photographs of the sensitive volume are taken on 60 mm 5G91 recording film (by Ilford Ltd.), using lenses of $2\frac{5}{8}$ in. focal length and a stereo angle of 10°. The object distance is 22 in. giving a mean magnification of $0{\cdot}12$ over the field. The lenses are Dallmeyer "wide angle anastigmats" which, as a result of measurements described below, have replaced the Dalmac lenses originally used. At present xenon filled flash tubes made in this laboratory which dissipate 200 J per flash are employed. An aperture of $f/8$ is used compared with $f/11$ when 400 J tubes are available. The larger aperture does not result in the sharpest definition over the full depth of the sensitive volume, but does so over the 1 cm depth to which the primary particles are restricted by external collimation. The slight loss of definition for the tracks of secondary particles is of small importance because of the greater width of the tracks of more heavily ionizing particles. The overall resolution of good lenses and high speed film results in a circle of confusion of diameter about 20 μ.(8) The images of tracks of minimum ionization density are in fact found to be 20 μ wide. This indicates that a somewhat greater magnification might be desirable for the greatest accuracy in curvature measurement, but this could not be tolerated on grounds of economy in film consumption. A flash delay time of about $0{\cdot}100$ s is necessary for the satisfactory recording of the tracks of minimally ionizing particles in hydrogen at a pressure of 25 atm.

OPTICAL DISTORTION

The requirements which must be satisfied by lenses for use in photographing cloud chamber tracks have been considered by Wilson(5) and Newth.(8) The general form of the distortion curvatures introduced by lenses has been discussed by Blackett.(9) Since the magnitude of the distortion is symmetrical about the optic axis but the value changes sign at the axis, the displacement of the image of a point due to distortion is radial and may be written as a series in odd powers of the distance from the axis:

$$\delta r = a_1 r + a_2 r^3 + a_3 r^5 + \ldots\ldots \qquad (1)$$

where r is the distance of the undistorted image point from the axis, δr the displacement due to distortion and a_1, a_2, etc., are constant coefficients. The linear term merely represents a change in magnification and introduces no curvature. If three terms are sufficient to represent the distortion accurately Blackett shows that the equation of the image of a straight line is:

$$y = a_2 y_0^3 + a_3 y_0^5 + (a_2 y_0 + 2a_3 y_0^3)x^2 + a_3 y_0 x^4 \qquad (2)$$

where x and y are rectangular co-ordinates and y_0 is the length of the perpendicular from the optic axis onto the undistorted image of the line. For regions of the image close to this perpendicular the curvature will be approximately circular and given by

$$\sigma_{circ} = 2a_2 y_0 + 4a_3 y_0^3 \qquad (3)$$

with σ_{circ} the circular component of image curvature defined as the reciprocal of the radius of curvature. Thus the distortion of a given lens may be specified by plotting σ_{circ} versus y_0 for a series of images of straight lines at different distances from the optic axis.

The presence in the optical system of the glass plate used to seal the chamber will give rise to distortion. It can be shown that, for a plate of thickness t and refractive index μ:

$$\delta r = \frac{t}{u}\left(1 - \frac{1}{\mu}\right)r + \frac{t}{2uv^2}\left(\frac{1}{\mu} - \frac{1}{\mu^3}\right)r^3 + \\ + \frac{3t}{8uv^4}\left(\frac{2\mu^2 - \mu^4 - 1}{\mu^5}\right)r^5 \quad (4)$$

with u and v the object and image distances respectively. The higher order terms in equation (4) are negligible for $r/v < 1$. It follows that the curvature in the image due to the glass plate is, under the same conditions as for equation (3)

$$\sigma_{circ} = \frac{t}{uv^2}\left(\frac{1}{\mu} - \frac{1}{\mu^3}\right)y_0 + \frac{3t}{2uv^4}\left(\frac{2\mu^2 - \mu^4 - 1}{\mu^5}\right)y_0^3 \quad (5)$$

Further distortion will arise if the surfaces of the glass plate depart from flatness. The deviation $d\phi$ in a ray making an angle θ with the normal to the mean plane of the glass surface due to a local angular error $d\theta$ in either surface is

$$d\phi = d\theta\left(\sqrt{\frac{\mu^2 - \sin^2\theta}{1 - \sin^2\theta}} - 1\right) \quad (6)$$

for $d\theta$ small. The maximum value of θ in this case is 23° so that $0{\cdot}50\, d\theta \leqslant d\phi \leqslant 0{\cdot}56\, d\theta$ over the field for $\mu = 1{\cdot}5$. Thus if the tolerable linear displacement in the object plane is $\delta r'$, the angular tolerance $\delta\theta$ for random errors in either surface of the glass plate is:

$$\delta\theta = \frac{\delta r'}{\sqrt{(2)}u' \sec^2\theta} \cdot \frac{d\theta}{d\phi} \quad (7)$$

where u' is the distance of the plate from the object. The weak dependence of $d\phi$ on θ results in a tolerable lack of parallelism of the glass surfaces of about $10\,\delta\theta$.

The bending of a glass plate when subjected to stress as in a high pressure cloud chamber may be shown$^{(10)}$ to yield a maximum angular deflexion $d\theta$ bending of about 10^{-4} radian. However, the surfaces of the plate remain parallel under bending so that the net angular error of a ray traversing the plate is due to the difference between the surface angles at which it enters and leaves the plate. Moreover the bending of the plate is symmetrical about its centre so that curvature in the image is only introduced by the non-linear terms in the relationship between displacement and radius. Numerical calculations show that curvature errors due to bending are very small in the present case.

METHOD OF MEASUREMENT

The lenses and the complete optical system were tested by photographing a rectangular network of taut nylon fibres on N40 process plates (by Ilford Ltd.) to avoid the bending which might occur with film. Fibre does not kink and nylon has a high tensile strength to mass ratio. The fibres were 0·2 mm in diameter and were stretched to a tension of 200 g wt. at which the effect of sagging is negligible.

The microscope used for the co-ordinate measurements on the plates was a type 4000 (by Cooke, Troughton and Simms Ltd.) in the adaption designed for nuclear research with photographic emulsions. It was fitted with a stage movable in two directions at right angles by 25 mm micrometers. Objective of magnifications ×5 and ×10 were used with ×15 eyepieces. By alining a cross-hair in the eyepiece with the centre of the fibre image readings reproducible to 1 or 2×10^{-4} cm were obtained. The curvature of the stage motion was measured by determining the co-ordinates of a series of points along a fibre image. The plate was then rotated through 180° in its own plane and the co-ordinates of the same points re-determined. If the curvature of the image is σ_l and that of the stage motion σ_s, then the measured curvatures will be $\sigma_s + \sigma_l$ and $\sigma_s - \sigma_l$ and their sum $2\sigma_s$. The curvatures were calculated by the least square procedure described below and σ_s found to be $0{\cdot}01 \pm 0{\cdot}015\ \mathrm{m}^{-1}$.

The curvature of each fibre image was calculated by fitting the equation

$$y = a + bx + cx^2 \quad (8)$$

to the measured co-ordinates by a least squares method. It only errors in y, the co-ordinate perpendicular to the mean direction of the track, are significant as is true for small curvatures it can be shown$^{(11)}$ that the most probable value of c is given by:

$$C = \frac{n\sum_1^n x_r^2 y_r - \sum_1^n x_r^2 \sum_1^n y_r}{n\sum x_r^4 - (\sum x_r^2)^2} \quad (9)$$

where $(x_1, y_1)\,(x_2, y_2) \ldots (x_r, y_r) \ldots (x_n, y_n)$ are the measured co-ordinates. The curvature of the fitted curve is

$$\sigma = \frac{d^2y/dx^2}{[1 + (dy/dx)^2]^{3/2}} \simeq 2c \quad (10)$$

for an image alined parallel to the x axis to make b small. The probable error $\delta\sigma$ for an image of length l and y values subject to a probable error δy can be shown to be

$$\delta\sigma = \frac{4\sqrt{(45)}(n-1)^2}{\sqrt{[n(n^2-1)\,(n^2-4)]}} \cdot \frac{\delta y}{l^2} \quad (11)$$

where n is the number of pairs of measured co-ordinates. The variation of $\delta\sigma$ with n is slow so that large numbers of readings are not justified. In practice an image length of 2 cm and x co-ordinates 0·25 cm apart were used. The assumption of circular curvature is then valid if a_3 is not too large relative to a_2 (equation 3). For the image length mentioned above and $\delta y = 1\ \mu$ the value of $\delta\sigma$ is $0{\cdot}02\ \mathrm{m}^{-1}$. The curvature of an image can be calculated from the co-ordinates in less than one minute using a conventional mechanical calculating machine. The superiority of this procedure over that of computing the curvature from points plotted graphically on a distorted scale should be emphasized. For the latter case, only the points near the ends and centre of the image are effectively used in any simple derivation of the curvature.

CONVECTIVE DISTORTION

The conveyance of ions and drops from their points of formation by the macroscopic motion of the gas may be very serious in a diffusion chamber because of the large vertical temperature gradient required for satisfactory operation. Whilst for the Birmingham chamber this temperature gradient is positive upwards so that the situation is inherently stable, the details of chamber construction and the presence of eddy currents in the walls due to the pulsed field lead to azimuthal variations in temperature and convective gas flow. The ual observation of tracks which take several seconds to through the sensitive volume indicated that the most portant effect was a gas flow into the large apertures minated by the windows through which the chamber is minated. This flow occurred near the base of the chamber l was presumably due to the windows being at a somewhat her temperature than the walls in the vicinity. It has been ctively eliminated by fitting thin glass sheets over the rtures thereby isolating the gas within them from the sitive volume.

Gas motion also results when streams of ions leave the aring field electrode due to the presence of dust or fibres. hough the electric field is removed several seconds before entry of the proton beam such streams easily persist for length of time. The electrode must be clean and smooth avoid this effect.

The residual convective distortion was measured by ermining the curvatures of the tracks of 1000 MeV tons in zero magnetic field. The photographs on which se measurements were made were taken under typical rating conditions with a chamber filling of hydrogen at a ssure of 25 atm and a flash delay time of 0·100 s. It s necessary to use film for these photographs since a table emulsion is not available on plates. The flatness uirements for the film are somewhat stringent, the pro- tion of any displacement onto the mean plane of the film ng about one-third of the displacement at the maximum gle at which the lens views. A high degree of flatness is ured by a spring loaded glass backing plate which forces film against a stainless steel plate containing the aperture ich is the field stop of the optical system. Comparison of curvatures of corresponding fibre images on plates and n showed that the effects of film bending and processing tortion were negligible over the field of view. After cessing the film was clamped between glass plates and the vatures of 30 tracks distributed throughout the sensitive lume were determined. The length of track used was about cm. The direction of the tracks was at right angles to the e joining the lens axes. The procedure was similar to that scribed above for the measurements on fibre images.

RESULTS AND DISCUSSION

The results of the measurements on the Dallmeyer Dalmac d "wide angle anastigmat" lenses are given in Figs. 2(*a*) d (*b*) as graphs of the circular component of curvature rsus the distance from the axis, each in the image plane. e symmetry and smoothness of these curves, together with e essentially zero curvature on the optic axis, demonstrate at the assumption of axial symmetry is valid and that dis- rtion of the emulsion during processing is small. The fitted rve in Fig 2(*a*) is a plot of equation (3) with $a_2 =$ 0 × 10^{-4} cm^{-2} and $a_3 = -1\cdot8 \times 10^{-4}\ \mathrm{cm}^{-4}$. It follows m the finite value of a_3 that a fourth power term exists the distorted image of a straight line. This causes a riation in curvature along the line such that the maximum rvature is much greater than the value at the centre. A e 1·5 cm from the axis varies in curvature from 0·18 m^{-1} ar the centre to about 1·4 m^{-1} at the extreme edge of the ld. The latter figure corresponds to an error of about 40% the momentum of a 1000 MeV proton. Whilst this large rvature occurs only at the extreme edge of the field it is ar that the average value is large and the form of the riations of distortion curvature makes the application of rrections difficult.

From Fig. 2(*b*) for the wide angle lens the coefficient a_3 is zero within the accuracy of the measurements and a_2 has the value $(1\cdot05 \pm 0\cdot2) \times 10^{-4}\ \mathrm{cm}^{-2}$. Thus the curvature introduced by this lens is of small magnitude over the field and is circular in form. This makes the application of corrections comparatively simple. A further advantage of this lens is that the definition is maintained to the edges of the field whereas some falling off in definition was found with the Dalmac lens. It should be noted that the aperture of *f*/8 is intended by the manufacturers for focusing only, but no trouble has been experienced over the 45° angular field used in the diffusion chamber when the lens is used at this aperture.

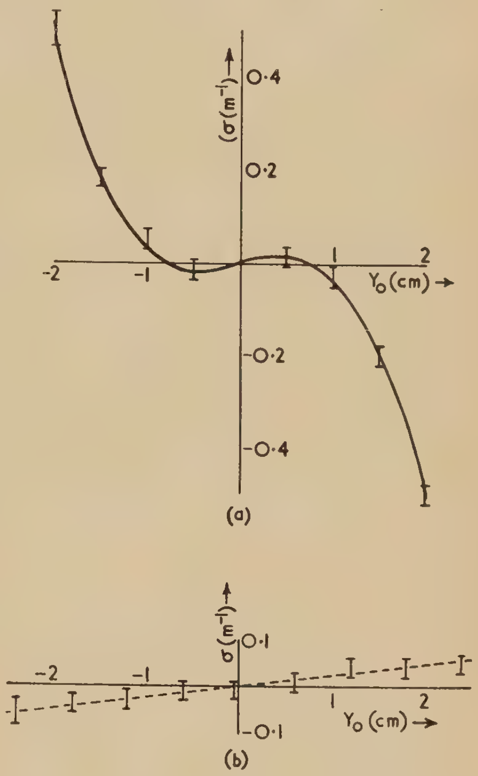

Fig. 2. Distortion of: (*a*) Dalmac lens (the fitted curve is a plot of equation (3) with: $a_2 = 2\cdot0 \times 10^{-4}\ \mathrm{cm}^{-2}$, $a_3 = -1\cdot8 \times 10^{-4}\ \mathrm{cm}^{-4}$), (*b*) Dallmeyer "wide angle" lens

σ = central curvature.
Y_0 = distance from axis.

The effect of a glass plate in the optical system has been discussed previously. Measurements of the curvatures introduced into the images of straight lines by an optical system containing a 1¼ in. thick disk of armour-plate glass revealed distortion curvatures which varied in an erratic manner across the field. Fibre images which intersected the optic axis possessed curvatures of order 0·5 m^{-1} indicating that the distortion was not radial. Examination of the surfaces of this and similar glass disks by interferometric methods revealed local surface irregularities sufficiently in excess of the limit calculated from equation (7) to account for the observed distortion. The defects appear to be inherent in the method of manufacture of armour-plate. This material has apparently been found satisfactory for expansion cloud chambers because of the small value of u' [equation (7)] in conventional designs. This situation will also apply for bubble chambers.

A design which would dispense with the use of armour-plate was sought for the Birmingham cloud chamber. A window of plate glass must be of small diameter because of the prohibitive thickness required to withstand the high pressure when large diameter windows are used. It is evident from equation (5) that for a given magnification the circular component of curvature in the image varies inversely as the cube of the focal length of the lens used. Comparatively large thicknesses of glass could be tolerated if lenses of long focal length were employed. However, such lenses are expensive and the necessarily large object distance would be mechanically inconvenient in addition to requiring a larger aperture in the magnet yoke. For applications in which these factors are of lesser importance lenses of greater focal length might be considered because of additional advantages attendant upon their use, i.e. more nearly orthogonal projection reducing the corrections for conical projection when measurements are made on the film, and low distortion because of the small angular field. For the present application it was decided to make the windows as thin as possible consistent with safety. The price of optically polished glass was considered prohibitive because of the danger of breakage, but selected pieces of $\frac{1}{2}$ in. plate glass of $2\frac{1}{4}$ in. diameter and flat to 3 fringes per inch (3×10^{-5} radians) were obtained from Messrs. Pilkington Bros.

The overall distortion of the system in its final form is shown in Figs. 3(*a*) and (*b*). Distortion due to surface errors in the glass plates is less than the experimental errors. From Fig. 3(*b*) the coefficient $a_2 = 2 \cdot 1 \pm 0 \cdot 1 \times 10^{-4}\ \mathrm{cm}^{-2}$ which compares with the sum of the measured coefficient for the lens and the calculated coefficient for the glass plate which is $2 \cdot 0 \times 10^{-4}\ \mathrm{cm}^{-2}$. The asymmetry in Fig. 3(*a*) is due to the 5° angle between the optic axis and the normal to the glass plate. As shown in Fig. 1 the lenses are inclined to reduc the angular field. This introduces some inconvenience sinc the origins of lens and plate distortions are displaced, bu this is slight as is the increase in the maximum distortion.

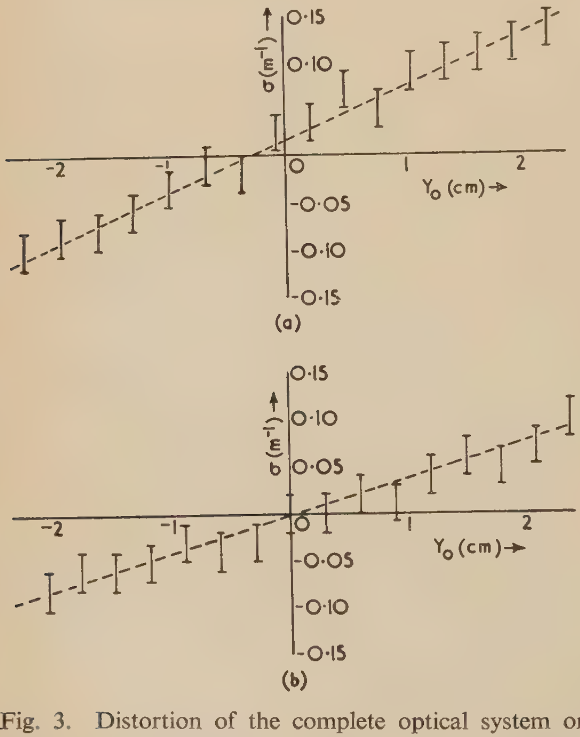

Fig. 3. Distortion of the complete optical system on two image diameters at right angles. (*a*) Y_0 in plane of lens axes, (*b*) Y_0 perpendicular to plane of lens axes

σ = central curvature.
Y_0 = distance of lens axis.

Fig. 4 is a distribution of the convective distortion curva tures measured as described above and corrected for optica distortion. The average value of $0 \cdot 05\ \mathrm{m}^{-1}$ on the film corresponds to an error of 2% in the momentum of 1000 MeV proton in a magnetic field of $1 \cdot 3 \times 10^4$ G. Th maximum detectable momentum is thus $8 \cdot 5 \times 10^{10}$ eV To attain this accuracy with the present technique of measur ment a track length of about 20 cm is required. Measur ments on some shorter tracks indicated that convective dis tortion curvatures are not significantly greater for such tracks. Thus for tracks of length less than 20 cm the limit of accura is set by measuring technique and the error is given equation (11). For tracks appreciably longer than 20cm only the convective distortion error is important.

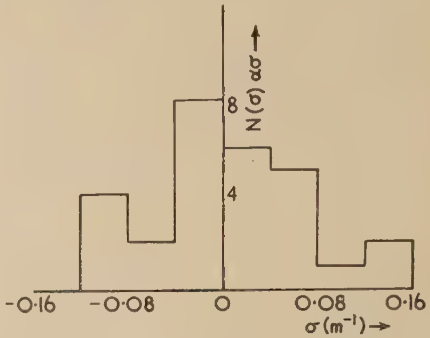

Fig. 4. Histogram of convective distortion curvatures

σ = curvature.

ACKNOWLEDGEMENTS

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Laboratory and workshop notes

An attachment to a Weissenberg camera for heating specimens between exposures

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is device has been developed for studying those hydrated cates and aluminates which dehydrate to give ordered ducts, but it could be used to study any irreversible rmal transformation in which orientation is preserved. termination of the orientation of the product relative to t of the starting material may give useful information out the mechanism of the change.

Attachments to single crystal goniometers enabling oscil- on and rotation photographs to be taken at high tem- atures have already been described.(1,2,3) All the required ormation can be obtained using these, by plotting sets of illation photographs taken about some axis which has n shown to be preserved. This method is tedious, and changes not reversible with temperature the present achment to a Weissenberg goniometer can be used and atly reduces the labour. Moreover, with badly crystalline terials, it gives more accurate results.

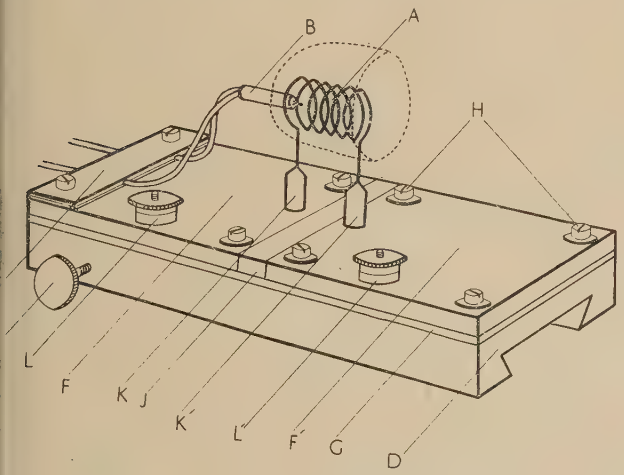

Fig. 1. General view of the attachment

Fig. 1 shows a general view of the attachment. The nace *A* consists of six turns of 18 gauge Nichrome wire ound into a spiral about 7 mm in diameter. It is lagged th a layer of asbestos tape, and the whole is coated with heat-resistant compound made by mixing aluminous cement to a paste with water-glass diluted with an equal volume water. This insulation (indicated in Fig. 1 by broken es) also closes one end of the furnace, and a chromel–umel thermocouple *B* mounted in twin-bore silica tubing, set into this end with the hot junction inside the furnace. e flexible leads to the thermocouple are secured to the ounting by a clamp *C*.

The brass slide *D* is designed to fit on to the Weissenberg mera in place of the cassette and is provided with a locking rew *E*. This slide carries two brass plates *FF′* insulated om it by a sheet *G* of ⅛ in. Tufnol and attached by insulated rews *H*. The gap between the plates is filled with a strip *J* grey Sindanyo to protect the Tufnol from direct radiation from the furnace. Two brass pieces *KK′* are screwed into the plates, and the furnace leads are soldered into these. Power is supplied through the two heavy brass terminals *LL′*.

The power supply is low voltage–high current, and when giving a temperature of 1000° C in the centre, the furnace consumes about 17 A at 3·5 V; i.e. about 60 W. Since the furnace is so small, the temperature gradients are steep, but calibration with another thermocouple showed that, provided the crystal was placed level with the thermocouple junction and within 2 or 3 mm of it, its temperature would be within 20° of that recorded. Greater accuracy was not required, and no attempt at improvement was made.

The crystal was mounted as described by Dent and Taylor,(3) except that waterglass alone was replaced by the cement mentioned above.

The crystal is set about an axis (possibly not a major crystallographic axis) which oscillation photographs have shown to be preserved. The goniometer head is mounted on the Weissenberg camera. The lower half of the layer-line slit is blocked with a thin strip of brass, and a 180° Weissenberg photograph is taken on the upper half of the film. The cassette and screens are removed. The cassette carriage is locked in the central position, and the attachment adjusted on the slide so that the thermocouple junction is as close as possible to the crystal. Should the crystal not coincide with the axis of the thermocouple, it can be moved, using the lateral adjustments of the goniometer head.

The crystal is heated until the transformation is judged to be complete. After removal of the furnace, the cassette and screens are replaced exactly as before, but with the brass strip blocking the upper half of the layer-line slit so that the

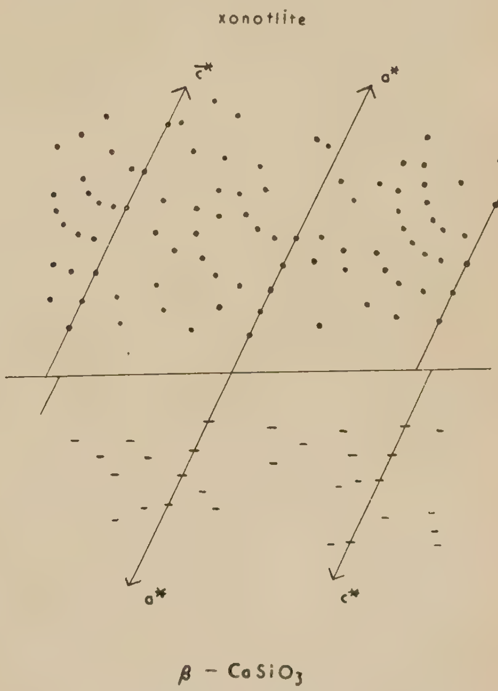

Fig. 2. Tracing of a composite Weissenberg photograph obtained using the attachment. *Upper half*: xonotlite h01 layer. *Lower half*: the same crystal after heating at 700–800° C showing conversion into β-$CaSiO_3$. No attempt has been made to represent relative intensities

lower half of the film is exposed. A further 180° Weissenberg photograph is taken.

Provided that the cassette has been replaced exactly in its original position, the two halves of the film give the relative orientation of starting material and product. Fig. 2 is a tracing of such a photograph. The mineral xonotlite, $Ca_6Si_6O_{17}(OH)_2$, dehydrates to β–$CaSiO_3$ (wollastonite or parawollastonite) on heating at 700–800° C. Oscillation photographs show that the *b*-axis is preserved. (Both substances are monoclinic, with $\beta = 90°$ in xonotlite and $\beta = 95°24\frac{1}{2}'$ in β–$CaSiO_3$.) The upper half of the photograph shows the h01 layer of xonotlite, and the lower half the corresponding layer for β–$CaSiO_3$. There is more disorder in the β–$CaSiO_3$, but the figure shows that the direction of a^* is preserved.

I am grateful to Mr. J. G. Thomas and Mr. A. F. Mess for their help in the construction of the attachment.

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The application of a simple mercury discharge lamp to Schlieren photography

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[*Note received* 10 *August*, 1956]

In Schlieren systems used for the display of plane detonation or shock waves it is desirable to employ a line source of high intensity. Many of the commercially available mercury discharge lamps are unsuitable for this purpose owing to the relatively large dimensions of their sources. Of these the Mazda type BH-6 lamp, which has an effective source of about 1 mm × 25 mm, appears to be best suited for this work and its use in a Schlieren system has been described by Barnes and Bellinger.(1)

For the "streak" recording of detonation waves on a drum camera, the authors have found that a simple lamp, constructed from fused quartz tube and operated at atmospheric pressure, provides a satisfactory source. Such a lamp appears to have been first described by Wilson(2) and was used extensively at one time in cloud-chamber photography. The manner in which the lamp may be operated continuously has been described by Weller,(3) and its use as a stroboscopic source has been described by Frankl(4) who used the lamp in conjunction with an ignitron. The lamp described here is of simpler design than those given by the above authors and can be easily constructed without the assistance of a skilled glassblower.

A diagram of a section of the lamp is shown in Fig. 1. It consists of a length of quartz tubing (1 or 2 mm bore and 2 mm wall thickness) bent into the form of a U, to the ends of which are attached, by means of rubber sleeves, pieces of glass tube, which form the reservoirs. The system is filled with mercury and steel wires are inserted to form electrodes; these wires are of slightly greater diameter than the bore of the quartz tube and are tapered over a length of approximately $\frac{3}{4}$ in. in order to prevent the formation of an air bubble between the electrode and the mercury. A short length of eureka wire (about No. 28 s.w.g.) is wound about five times around the point *X* of the tube to act as a heater. Sufficient current is passed through this to produce a column of mercury vapour of about $\frac{1}{4}$ to $\frac{1}{2}$ in. long at *X*. The closely fitting steel electrodes allow the mercury to flow slowly past during heating but damp out any tendency of the mercury to oscillate and prevent it being blown out when the discharge occurs. Asbestos fibre, packed into one or both limbs of the U-tube, provides additional damping of the mercury column and improves the performance of the lamp when running continuously.

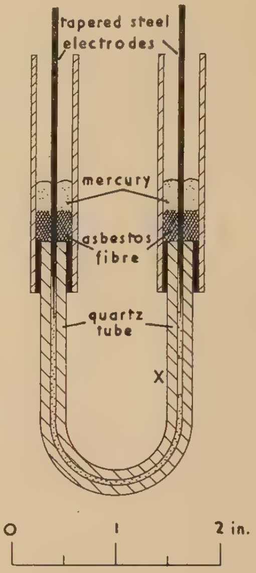

Fig. 1. Section of mercury discharge lamp

A type CV.12 mercury-vapour thyratron is used to discharge a condenser of 7 μF at 3 kV through the lamp. A diagram of the circuit is given in Fig. 2. The discharge is initiated by opening the switch *S* which is usually a simple "inertia-switch" of the type described by Davies.(5) A variation of flash duration of approximately 10 to 500 μs is obtained by varying a small inductance in series with the lamp. It was found necessary to connect a resistance of 3000 Ω in parallel with the discharge lamp as the high resistance of the lamp otherwise prevents the thyratron from striking. For purposes of making adjustments of the optical system the lamp may be run continuously by connecting the electrodes to a 220 V d.c. supply in series with a ballast resistor (1000 Ω is found to be convenient) and a choke of

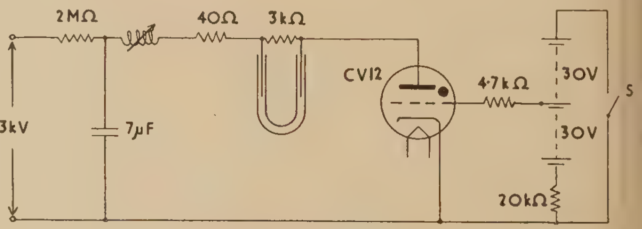

Fig. 2. Diagram of flash circuit

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* Now at the British Cotton Industry Research Association, Shirley Institute, Didsbury.

uctance between 10 and 20 H which improves the stability he arc.

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(3) Weller, R. *Rev. Sci. Instrum.*, **6**, p. 289 (1935).

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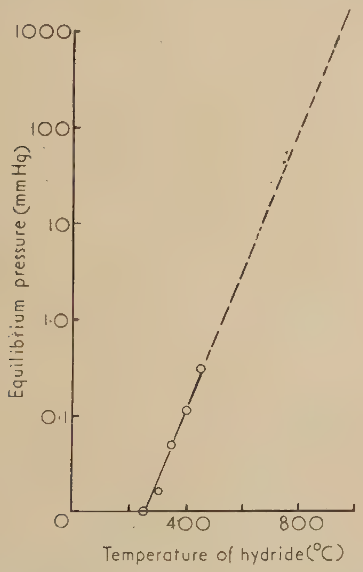
(5) Davies, R. M. *Phil. Trans Roy. Soc. A*, **240**, p. 375 1948).

NOTES AND NEWS

Correspondence

On processing titanium hydride replenishers

“hydride replenisher” has been used to maintain the ssure of hydrogen in thyratrons for several years.* The st suitable hydrides are those of the Group IV elements nium, zirconium, hafnium and thorium. These have a ıcture intermediate between a chemical compound and a d solution, a given mass of metal being capable of absorb- a continuously varying quantity of hydrogen up to a ximum corresponding to the usual chemical formula I_2. For a given composition of hydride, there is an ilibrium pressure of hydrogen which increases mono- ically with temperature. This behaviour for titanium lride is illustrated in Fig. 1, taken from a curve given by lly and Harbaugh. It is this property that is used in the



ig. 1. Equilibrium hydrogen pressure as a function of itanium hydride temperature (the points on the graph are taken from Reilly and Harbaugh)

lenisher. The hydride is placed in a capsule that can be ted, within the vacuum envelope of the valve. When nparatively small amounts of hydrogen are “cleaned-up” valve electrodes, the hydrogen pressure is maintained by hydride at the equilibrium pressure corresponding to the lride’s composition at its working temperature.

For the present application, titanium hydride was used. This is a grey-black powder, stable in air, which is fairly easy to compress into pellets. It is commercially available in a form usually stated to have 1·6–1·8 atomic parts of hydrogen to one part of titanium. The replenisher capsule was a copy of one designed by the Research Laboratory of the General Electric Co. Ltd. for use in thyratrons, in which titanium hydride pellets could be heated by a spiral tungsten heater. The valve in which it has been used by us is a microwave coaxial diode attenuator.† Attenuation of the microwave signal is achieved by a gas discharge in a coaxial line. The gas used is argon, with a small partial pressure of hydrogen. The function of the latter is to shorten the electron attachment time (“recovery”) of the gas after the discharge ceases. This recovery time, an important parameter in the working of the valve, is dependent upon hydrogen pressure. Too little hydrogen gives an unacceptably long recovery time but too much decreases the attenuation during the discharge period by affecting the cathode temperature. It is the function of the replenisher to control the pressure between these limits, which are further discussed below, during the life of the valve. Two processing methods were tried.

Processing with a gas “bubbler” gives an accurate equilibrium pressure, but suffers from the disadvantage that the processing time on the pump varies from five minutes to about one hour for each replenisher.

After the valve has been baked on the pump, the replenisher is outgassed by heating to about 950° C. It is then allowed to re-absorb a predetermined quantity of hydrogen. The pump tap is then closed and the “bubbler” (Fig. 2) connected to the system. A fixed voltage is applied to the replenisher heater, which will liberate sufficient hydrogen for some to be pumped through the bubbler. The system is left until

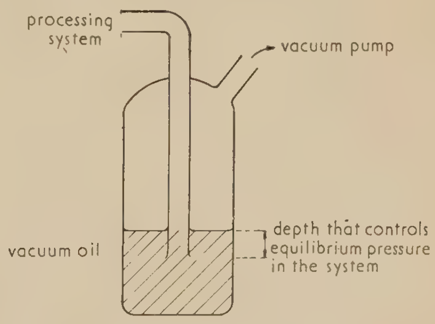


Fig. 2. The gas bubbler

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* Reilly and Harbaugh. U.S. Patent 2497911 (1950).

† Hawkins and Costain. *Nature*, **164**, p. 356 (1949).

bubbling ceases, when its equilibrium pressure corresponds to the depth of penetration of the inner tube in the oil. In subsequent operation, replenishers of the same mechanical design will give reproducible pressure characteristics, the absolute values being determined by three parameters only: (1) the heater voltage applied during processing; (2) the differential pressure in the bubbler, and (3) the volume of the pump system.

The prefilling method is very simple, the essential idea being that the hydride is heated in a hydrogen furnace shortly before the valves are assembled. The processing conditions are designed so that a high temperature is attained to outgas the pellets. They are cooled slowly so that hydrogen is reabsorbed at a temperature at which the reaction

$$Ti + H_2 \rightleftarrows TiH_2$$

proceeds rapidly. As the pellets cool below 900° C, the atmospheric pressure of hydrogen is in excess of the equilibrium so that the titanium becomes saturated (Fig. 1).

The process, therefore, is as follows. The pellets are placed in a silica boat lined with platinum, and heated in a silica tube furnace at 1000° C for ten minutes. The cylinder hydrogen that flows through the furnace is purified by a catalytic oxygen remover and a silica gel drier. After firing, the boat is pulled just out of the hot spot and left in a cooler part of the furnace for a further ten minutes. Finally it is cooled in the water jacket and removed. The pellets are stored in air-tight containers, and assembled into valves within twenty-four hours. When the valves are baked on the pump at 450° C there is some loss of hydrogen; this is made reproducible by controlling the baking time and temperature to within 5%.

The composition of the pellets could be found by fully outgassing them in the known volume of the pump system. This was done with four replenishers which initially had a composition $TiH_{1\cdot06}$ with a spread of ±6%. After eighty minutes baking, the composition was $TiH_{0\cdot30}$ with a spread of ±11%. Although this is a low proportion of hydrogen, 120 mg of the material are sufficient to give a pressure of more than 30 cm of mercury in the valve. It is thus an adequate reservoir to maintain a pressure of 0·5 mm of mercury.

The processing method described above has been used to make a pre-production batch of microwave diode attenuators. The replenisher capsule is run at a fixed heater voltage and the variation of hydrogen pressure produced is represented by the spread of recovery times for the valves given in Fig. 3. The change in recovery time with partial pressure of hydrogen is shown in Fig. 4. From these results it can be seen th 93% of the valves have hydrogen pressures, at a fixed suppl voltage, in the range 0·47 ± 0·09 mm of mercury.

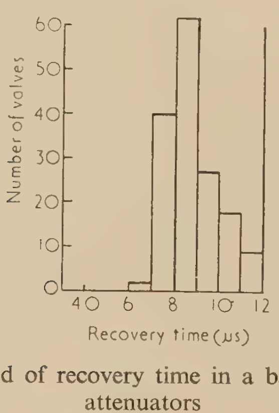

Fig. 3. Spread of recovery time in a batch of coaxial attenuators

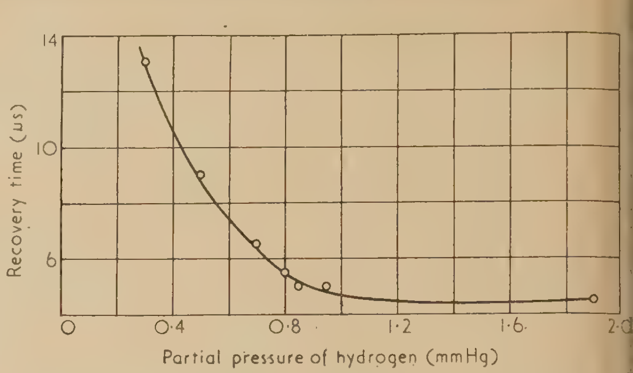

Fig. 4. Variation of recovery time with hydrogen pressure for a typical valve

The effect of hydrogen "clean-up" on equilibrium pressur a phenomenon of primary importance for valve life, can b observed by pumping known amounts of hydrogen awa from a valve on the pump system and observing the chang in equilibrium pressure. In Fig. 5 the equilibrium pressu is plotted against the amount of hydrogen removed, expresse as a pressure change in the volume (20 cm³) of the valve In experimental valves without replenishers a clean-up rate o approximately 0·5 mm of mercury in 100 hours has bee observed. To get a very conservative estimate of life it ma be assumed that this rate is maintained, and that during th useful life, the hydrogen pressure falls by 0·3 mm of mercury This gives a life of 4500 hours, which has not been confirmed since other factors cause earlier failure. However, severa valves have had lives of between 1000 and 1200 hours. I could be predicted from the above calculation that ther would be no observable change in hydrogen pressure in thi time, which is in fact the case.

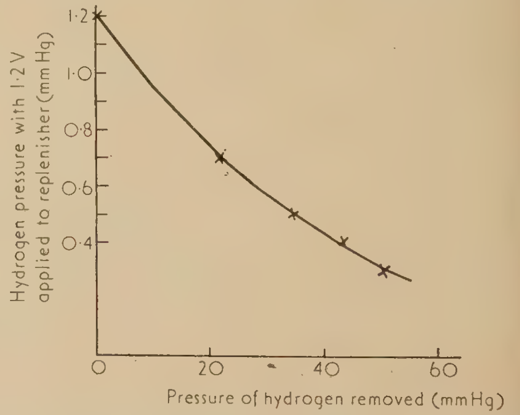

Fig. 5. Effect of removing hydrogen on equilibrium pressure of replenisher

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Laboratory Extn,
Harlow,
Essex.

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(16 October, 1956)

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* Now at Engineering Laboratory, University of Oxford.

Instruments, Electronics and Automation Exhibition, 1957

A PREVIEW

Instruments, Electronics and Automation Exhibition to be held at Olympia, London, from 7–17 May next will show the st advances in scientific instruments—laboratory, industrial and medical, automation and industrial control equipment, communications, radar and navigational aids, computers and many other applications of electronics and instrumentation.

he exhibition is promoted and actively supported by the following Associations: The British Electrical and Allied nufacturers' Association, The British Industrial Measuring and Control Apparatus Manufacturers' Association, The ish Lampblown Scientific Glassware Manufacturers' Association, The Drawing Office Material Manufacturers' and Dealers' ociation and The Scientific Instrument Manufacturers' Association of Great Britain Ltd.

dmission to the exhibition will be by tickets to be distributed by the exhibiting firms or upon payment of 2*s.* 6*d.* at the r; it will be open from 10 a.m. to 6 p.m. daily. There will be lectures each day on subjects relative to the exhibition.

or this preview we have selected, somewhat arbitrarily, a few items from each of those firms which replied to our invitation ubmit material. It should suffice to make clear how worth while a visit will be to Olympia next month.

eaders may like to know that a similar exhibition will be held at Olympia from 16–25 April, 1958.

ance Components Ltd., Roebuck Road, Hainault, Ilford, ex

stal calibrator. The type 74 crystal calibrator to be wn is a compact instrument designed for checking the bration of signal sources to a high degree of accuracy in range 1–250 Mc/s.

meter. The type T2 Q meter is an improved model with ch it is possible to compare coils against a standard.

ignal generators. The type 63 f.m./a.m. signal generator has n designed to meet the modern requirements of servicing f. television and radio receivers. It covers the range Mc/s to 230 Mc/s in six steps. The type D1 P/2 v.h.f. ial generator incorporates a 2 Mc/s reference crystal illator and a post attenuator crystal modulator which inates spurious frequency modulation. The six steps er 2–190 Mc/s.

ransformers. A range of constant voltage transformers also be exhibited.

mec Ltd., High Wycombe, Buckinghamshire

ctronic instruments. Several new instruments will be wn including the l.f. phase meter (type 206) which will asure both phase and gain in the frequency range 20 c/s– kc/s, as well as equipment for industrial electronic control measuring.

requency and time measuring equipment. Apparatus which measure and monitor time intervals from 100 μs to 00 s and frequencies from 0 to 31 Mc/s with an accuracy roaching 1 part in 10^7 will also be demonstrated.

tandard frequency equipment. One of the main exhibits on stand will be the standard frequency equipment developed the G.P.O. It employs an Essen ring-type crystal and has aily stability of better than 5 parts in 10^{10}.

is Brothers Ltd., Priory Works, Sarehole Road, Birming-, 28

g range signalling lamp. An improved model of the 's long range signalling lamp will also be on show.

ptical projectors. A range of 2 × 2 in. slide projectors be shown. The Aldisette 2 employs a 150 W lamp and Aldisette 3 a 300 W lamp.

oflow Engineering Ltd., Lawford Road, Rugby

s grinding machines. The Autoflow B.M.4 precision speed polisher is a flat and shallow curve polishing machine for blocks up to 15 in. diameter and incorporating the Autoflow patented pump in a new way. The arrangement allows for the work spindle to be run at various speeds independently of the pump. The Automag models 15/30 and 30/60 which will be shown are intended for producing steep curve lenses. The lens block spindle is mounted on a cradle having a swinging reciprocation movement and at the same time the work spindle counter revolves through 90°. The method of applying the polishing medium is by a drip feed through the polishing runner and the rate of drip is controlled by an adjustable magnetic device. The 158 Mark 2, which is an improved form of the firm's 4 spindle mass production diamond generator, will also be exhibited.

Baird and Tatlock (London) Ltd., Freshwater Road, Chadwell Heath, Essex

Apparatus for automatic chemical analysis. Among the instruments this firm will be exhibiting are the latest developments in B.T.L. Analmatic Series; these include an auto-titrator for making and recording measurements requiring a titration where a potentiometric or pH end-point is applicable, and a simple and robust double beam continuous flow absorptiometer. Other new instruments are a titration absorptiometer designed for the determination of calcium and magnesium in body fluids and giving accurate titrations at high dilutions with small volumes of sample; a valve-switching mechanism designed for applications where a gas is required to pass through a number of absorption tubes for one hour each, the prototype having been developed for air sampling to the requirements of the National Coal Board; and a liquid flow monitor designed to act as a safety device in a system through which it is necessary to maintain the rate of liquid flow to within close limits.

C. Baker of Holborn Ltd., 244 High Holborn, London, W.C.1

Surface finish interference microscope. The optical system in the instrument to be shown is after Mireau, and leads to a compact design in which the beams are only separated for a very short distance. Paired objectives are not required. Two powers of objective—×10 and ×40—are made and each power is now available with a reflectivity suitable for non-metallic surfaces, as well as the original lenses for metal specimens. The microscope is of original design and has doors which fold back in use; a camera is provided.

Transmitted light interference microscope. The sensitivity of the Baker-Smith interference microscope to be exhibited is considerably enhanced by the use of a special half-shade eyepiece. Another accessory is the fringe pattern eyepiece, made available for those wishing to employ the fringe-deformation method of measurement. A mercury vapour lamp had been developed for use with these instruments.

Baldwin Instrument Co., Ltd., Brooklands Works, Dartford, Kent

Densitometers. Two instruments which have been added to the range of densitometers will be shown. The comparator densitometer measures variation in colour and density of liquids, both static and in continuous motion. The new version of the line densitometer measures colour as well as density to a high degree of accuracy.

Nucleonic level indicator. The principle upon which this device works is that of material between a radioactive isotope and a detector which reduces the radiation intensity reaching the detector. In this instrument the detector is so designed that it can discriminate between the two intensities of radiation, operating suitable relays which in turn can operate either indication/alarm or automatic control systems.

Thickness gauge. Example of Atomat thickness gauges utilizing beta, gamma and bremsstrahlung radiation will be shown. By adding a further "deck" to the control cabinet, this firm's equipment can be arranged to standardize itself automatically.

Transverse profiler. The automatic transverse profiler which is being exhibited measures variation of weight per unit area of strips of paper or plastics cut from across the reel.

R. & J. Beck Ltd., 69/71 Mortimer Street, London, W.1.

Automatic grinding and polishing machine. With this machine metallurgical specimens can be prepared for etching in about 15 min.

Microscopes. Among the microscopes to be exhibited will be the No. 56 Research binocular microscope which has a new versatile stand having built-in illumination for transparent specimens.

Stereoscopic binocular with objective turret. This instrument comprises a versatile low power binocular microscope which can be readily fitted to a variety of stands. The magnification range is from 4× to 120× and the objectives required to achieve this are permanently housed in a turret which rotates about a horizontal axis.

Other exhibits. Other items to be shown include: a range of flat-field microscope objectives (5×, 10×, 25×, 65× and 100×) for photomicrography, automatic rotary microtome for sections from 1–15 μ, micro-spectroscope and a crushing microscope for dust analysis.

Belling and Lee Ltd., Great Cambridge Road, Enfield, Middlesex

Electronic components. The start of a range of B.N.C. connectors for v.h.f. work will be shown, the main features of which are their low standing wave ratio mechanical strength and waterproof qualities. The five connectors at present under development consist of a free plug, a right-angled free plug, a free socket, a fixed socket and a bulkhead adaptor (socket to socket). The exhibit will include printed circuit connectors, nylon sockets and receiving aerials, flexible terminal blocks, fuseholders, plugs and sockets.

Bonochord Ltd., Lancaster Road, High Wycombe, Buckinghamshire

Electronic Stethescope. The Auditec, which will be the principal exhibit of this firm, consists of a metal probe and portable amplifier with controls for sensitivity and volume It is intended primarily for use in industry to assist in the maintenance of machinery and in the detection of faults and flaws in materials.

British Electrical Development Association, 2 Savoy Hill London, W.C.2

The importance of instrumentation and controls as a mean of increasing productivity without heavy capital costs will be stressed on this Association's stand by equipment supplied by various member firms.

British Federal Welder and Machine Co., Ltd., Castle Mill Works, Dudley, Worcestershire

Auto-feed equipment. In the larger field of automati machine tools the company are exhibiting a model showing the application of production flow to resistance welding and similar mass production techniques.

Synchronous controls. A new range of fully synchronou controls has been developed combining a high grade synchronous timing unit, capable of adjustment from one cycle and a phase shift heat control utilizing only two trigger thyratrons and no additional control valves.

Weld timers. A range of electronic multi-stage weld timers will be shown.

British Physical Laboratories, Houseboat Works, Radlett Hertfordshire

Electrical indicating instruments. The range to be shown includes 1 to 5 in. miniature meters. Switchboard meters are also available together with a range of Fulscale indicators having a 270° movement.

Electronic measuring and testing equipment. Two types of a.c. valve voltmeter will be exhibited and a pulse generator with pulse widths of from 40 mμs to 1 μs. This instrument includes a square wave source and has a variable trigger advance. Fixed pad and variable attenuators are also in the range, the latter being accurate to within 0·1 dB up to 100 Mc/s, with very slight change in accuracy to 250 Mc/s.

A frequency meter, signal generator and electrolytic condenser bridge will also be on display. This latter instrument has been re-designed to include the measurement of tantalum capacitors.

The British Rototherm Co., Ltd., Merton Abbey, London S.W.19

Bi-metal actuated thermometers. A wide variety of dial ranges, presentations, stem lengths and diameters of Rototherms will be shown. The head of the vertical models has been re-designed.

Mercury-in-steel thermometers and recorders. Distant reading and rigid stem models of mercury-in-steel thermometers with accompanying single and dual pen recorders and ancillary equipment will be shown.

Pressure recorders. Single and dual pen pressure, vacuum and compound recorders for pressures from 10 in. water gauge will be exhibited.

Vapour pressure thermometers. A wide range of vapour pressure thermometers for industrial and other purposes will be displayed.

e British Thomson-Houston Co. Ltd., Rugby

comprehensive range of electronic products for industry l research are being displayed by this Company, among ich are the following items.

lectronic balancing equipment. The Rotobalance equip- nt for vibration analysis and the final balancing of all s of machines with the minimum of test running, will be wn. Phase, amplitude, and velocity of vibration data is duced in readily-plotted form, whereby size and location the balance weights required are clearly indicated. Pro- ced in three forms for shaft speeds from 100 to 30 000 r.p.m.

ptical tachometer. The firm's frequency meter incor- ating junction transistors and germanium diodes, can be dified to measure the speed of rotating shafts. Signals m the photoelectric equipment responsive to a mark on rotating shaft are fed into the frequency meter which es direct readings of the frequency of the signals, i.e. the ed of rotation of the shaft.

ortable leak-detector. A device which will detect leakage halogen gases at a very low leakage rate will be shown in . If the appliance under test does not already contain a ogen-bearing compound, a small amount is injected and system put under pressure.

ortable optical vibration meter. This instrument is for estigating the characteristics of vibration of surfaces and lies under test. Light from an integral lamp reflected m the vibrating surface affects a photo-transistor, the put of which drives a transistor amplifier connected to d-phones or an oscilloscope.

ortable vibration measuring equipment. This equipment vides vibration measurements over a wide range of quency and magnitude. It weighs only 32 lb., and can be d on any standard a.c. supply. Measurements of vibration h indications of size and frequency of the principal com- nents appear as meter readings and at the same time the ration is displayed on an oscilloscope.

yrometer. The transistor self-balancing pyrometer will shown in which a lead sulphide cell is used to compare ernatively infra-red radiations from a hot body with that a standard lamp with continuous adjustment of the current the lamp circuit by a transistor. The equipment records m 150° C upwards.

mbridge Instrument Co. Ltd., 13 Grosvenor Place, London, V.1

struments for science and industry. The wide range of the est measuring instruments which will be shown for use in lustry and science comprising equipment for indication- cording and control by electrical, hydraulic and pneumatic thods, will include instruments for the following purposes: nperature measurement, boiler control, electrical measure- nts including dynamometers, galvanometers, etc., physical d chemical analysis and research, including pH meters and larographs. Instruments for use in medicine and physiology ll also be shown.

Electronic recorder controller. This instrument which, its recorder form, employs a powerful closed-loop servo- stem of high sensitivity, accuracy and a fast speed of sponse, will measure any quantity that can be converted to a small direct current or voltage. Full scale traverse is der 2s and ranges can be supplied down to 1 mV or 0·2 μA ll scale. The recorders will respond to a change of input nal of less than 0·1% of full scale and accuracy is better an 0·5% of full scale on all ranges, these can be changed ite simply on site, the amplifier replaced within minutes, and chart speeds ranging from ½ in./h to 6 in./min selected by hand change gears. Supplied for single or multi-point operation up to 6 points (more using external switch) and for surface or panel mounting (dotting speed: standard 6s.; special 3s.).

Rotary-rocking microtome. This is a new rigid and robust instrument with a well-balanced hand-operated action suitable for producing long ribbons, of large area, with minimum fatigue. The mechanism has new features and is completely enclosed in an easily cleaned metal casing.

C. F. Casella and Co. Ltd., Regent House, Fitzroy Square, London, W.1

The following groups of instruments, taken from the firm's range of products will be demonstrated.

Humidity indicating and recording equipment. This ranges from simple Masons hygrometers, whirling hygrometers and motor-driven aspirated hygrometers capable of measuring relative humidities between −10 and +100° C, to dew-point instruments and frost-point hygrometers for indicating frost points down to nearly −90° C. Recording and indicating instruments incorporating human hair as the activating element will also be shown.

Miscellaneous laboratory research equipment. This includes a range of instruments for collecting samples of airborne dust or other particles, an airborne bacteria sampler and also a laboratory grain mill, recently added to the firm's range.

Pressure measuring equipment. A wide range of pressure measuring equipment will be shown as well as Pitot static-tubes and vane-type anemometers.

Casella (Electronics) Ltd., 46/48 Osnaburgh Street, London, N.W.1

Automatic particle-counter and sizer. This instrument counts and sizes particles in the range 2 to 100 μ using wide-track scanning and variable sensitivity.

Cathodeon Ltd., Church Street, Cambridge

Glass-metal seals. An exhibit will show a wide range of hermetic glass-metal seals.

Hermetically sealed switches. The basic design of these switches can be applied to a wide range of requirements in which protection from external conditions are required.

Television cameras. The range of cameras to be shown will include the Image Orthican used primarily for television work and the Staticon photoconductive camera tube for industrial and research installations. The Minicon tube which is only ½ in. in diameter and 3 in. long will also be shown.

A. E. Cawkell, 6–8 Victory Arcade, Southall, Middlesex

Electronic and acoustic instruments. A range of the firm's electronic and acoustic instruments will be shown and will include some new items among which will be the following:

Double three-phase 400 c/s power supply instrument. This exhibit consists of two entirely separate three-phase channels operating from a common power supply. The equipment is operated from a three-phase precision 400 c/s source and is capable of generating 150 VA per phase to either a delta or star connected load. The output voltage will remain constant to within 4% when the load is changed from zero to maximum. Numerous monitoring and safety devices are incorporated, and the equipment is designed to operate unattended continuously.

Generators. The Mark 2 pulse generator, the Mark 2 trigger generator, and a multiple pulse generator, will also be shown.

Mark 3 time calibrator. This instrument generates time markers on the range 0·5–1000 μ/s which may be free running, gated from an external gate, or gated from an internal gate having a continuously variable repetition rate of 1 μ/s to 10 m/s, and a continuously variable length of 2 μs to 100 ms. A crystal controlled checker is fitted. The markers are available individually from sockets controlled by switches, or combined to give a "timing-comb" type of presentation, variable in height, and either positive or negative going.

Cooke, Troughton and Simms Ltd., Haxby Road, York

Microscopes. The range to be shown will include the following: the Vickers projection microscope which is a universal instrument with a built-in camera, and stereoscopic microscopes; an inverted metallurgical microscope with built-in illumination, quintuple objective changer and "gliding" stage; the M25 and M35 series for research workers; the Dyson interferometer microscope which gives halo-free images of unstained living material; a variable amplitude phase-contrast microscope; polarizing microscopes including the Metalore microscope for metals and mineral ores (one of these microscopes will be shown with a point or particle counter); the M4000 universal microscope suitable for the most advanced and exacting work with transmitted or incident light.

Theodolites and levels. A complete range of theodolites from the Geodetic Tavistock theodolite for first-order work down to the vernier theodolite will be shown. Surveyors' levels covering every requirement will be exhibited.

Counting Instruments Ltd., 5 Elstree Way, Boreham Wood, Hertfordshire

Counters. This firm's display will consist primarily of electrically and mechanically operated counting units with and without resetting facilities, with variations devised to suit most industrial applications.

New developments to be exhibited (types 54/4 and 52/4) counting at rates up to 40 per second, and this has been achieved in the design of an escapement type of operating assembly energized from d.c. pulses of very short duration.

A further new instrument is a predetermining subtracting high speed counter, which can be set to any figure and subtract to zero where electrical contacts are made, so that a process can be stopped following a planned programme.

Crosby Valve and Engineering Co. Ltd., Ealing Road, Wembley, Middlesex

Control and relief valves. Several different types of control valve will be on the stand, as well as examples of safety and relief valves.

Level controllers. Another exhibit will be a working demonstration of a duplex-model Series 12800 air-operated displacement-type level controller.

Pressure controllers. Two air-operated Mason Neilon pressure controllers will be demonstrated, the Series 2700 and the Series 2800 having a pilot relay. A selector switch enables the performance of these two different models to be compared under working conditions.

Croydon Precision Instrument Co., 116 Windmill Road, Croydon, Surrey

Electrical measuring instruments. This company will be showing a comprehensive range of electrical measuring instruments which includes precision potentiometers, Wheatstone and Kelvin bridges, resistance boxes, and standards, strain measuring equipment, precision instrument and thermocouple switches. The switch exhibit includes both manual and motor driven switches, which are available with any number of positions up to 102. The main feature of these switches is low and constant contact resistance and negligible thermal e.m.f.'s.

Dawe Instruments Ltd., 99 Uxbridge Road, London, W.5

Electronic and acoustic instruments and equipments. A wide range of electronic devices will be exhibited, among which will be the following:

Type 442 v.l.f. oscillator. This exhibit is a commercial version of the Ministry of Supply inter-service oscillator C.T.365 and is a low distortion oscillator of particularly high stability. It provides quadrature outputs and covers the frequency range 0·1 to 10 000 c/s. Each output provides up to 25 V r.m.s. across a load of 10 kΩ and the total harmonic distortion of the 0° signal is less than 0·5%.

Type 1414 vibration indicator. This instrument is sufficiently small to be easily held in the hand and consists of a Rochelle-salt piezoelectric crystal accelerometer and a high-gain amplifier which employs subminiature valves and components.

Department of Scientific and Industrial Research, Charles House, 5–11 Regent Street, London, W.1

The department has organized a display of new instruments of a very diverse character. Many D.S.I.R. research stations and allied Research Associations have contributed and [illegible] different instruments will be shown.

A simple non-destructive thickness gauge for electrodeposits. This exhibit is from the British Non-Ferrous Metal Research Association.

Air-content of hydraulics oils. An exhibit from the Mechanical Engineering Research Laboratory.

An ionization chamber for the secondary standardization of radioactive material. An exhibit from the National Physical Laboratory.

Chromatic fraction collector. Single probe for testing thermal insulating materials. These exhibits are from the Food Investigation Organization.

Drying control instrument. This exhibit is from the British Leather Manufacturers' Research Association.

Dynamometer for textile testing with extensometer. This exhibit is from the Research Association of British Rubber Manufacturers.

Exposure calculator for gamma radiography. This exhibit is from the British Steel Casting Research Association.

Immersion viscometer. This exhibit is from the Fuel Research Station.

Instrument for measuring tension on running yarn. Single probe for measuring moisture in jute packages. These exhibits are from the British Jute Trade Research Association.

Lamination detector for the continuous inspection of strip. This exhibit is from the British Iron and Steel Research Association.

Micro-electro-magnetic vacuum balance. This exhibit is from the British Coke Research Association.

Microscope projection unit. Stiffness tester, Crease recovery tester. These exhibits are from the Shirley Developments Ltd., a company associated with the British Cotton Industry Research Association.

larographic dissolved oxygen recorder. An exhibit from Vater Pollution Laboratory.

essure transducer, Lustre meter, Yarn speed indicator, ronic tension meter, Strainometer, Warp tension meter, o tension comparator, Loom setting indicator. These oits are from the British Rayon Research Association.

ty Group Ltd., Cheltenham

rical and electronic products. In addition to a wide e of limit, micro, commutator, drum, lever and push- on switches together with lamp and electro-magnetic 2 3 position indicators, several types of high-speed elec- ic counting equipment will be shown by this Group. ber seals and mouldings of natural, synthetic and silicone er will also be displayed.

lier Condenser Co. (1925) Ltd., Ducon Works, Victoria l, North Acton, W.3

icitors. Metal cased tubular capacitors to be shown dielectrics of paper, metallized paper and Terylene film. y tropicalized capacitors with ceramic end seals will also splayed. Nitrogol capacitors are high performance paper citors produced in a wide range, including metal box s and plastic cased high voltage smoothing capacitors. ı capacitors to be shown include a full range of stacked and silvered mica capacitors, also the newly developed e forming networks, encapsulated in epoxy resin. A prehensive display of electrolytic capacitors will be oited. Capacitors for use in printed circuitry will include CRE/PC, which has a specialized fixing device, and a e of extremely small aluminium encased capacitors with terminations, also suitable for transistor applications.

esistors. BTS (½W) and BTA (1W) resistors with solder ed wire terminations are suitable for use in printed uitry. The BTA resistor is the latest addition to this e of completely insulated resistors and is rated at 1 W at C. A complete range of high stability carbon resistors ı ⅛ W to 2 W with tolerance of ±1½, 2 and 5% will be vn.

Electronics Ltd., Ekco Works, Southend-on-Sea, Essex

nters. A range of scintillation counters designed for in medicine, spectroscopy and general research and stry will be shown as well as the type N530 automatic er and timer for Geiger tube or scintillation counting.

ucleonic and electronic instruments. A range of nucleonic electronic instruments will be shown.

tric and Musical Industries Ltd., Hayes, Middlesex

tal weighing system. A feature of this exhibit will be a onstration of a newly-developed digital weighing system ng automatic control to precise limits of weighing, batching, ng or packing operations, with the output direct in ted form or in any other form readily acceptable by ronic digital computers for further processing.

lectronic instruments. Among other industrial electronic uments, three types of dynamic balancing machines for correction of unbalance in rotating parts will be shown. e types of stroboscope will also be exhibited as well as types of tachometer. Particularly suited to fast pulse wide bandwidth applications are measuring oscilloscopes [2 and WM5A; both will measure time intervals and a.c. and/or d.c. signals with accuracies of 2½%. Measuring oscilloscope WM4 and oscilloscope type 2300 are two remarkably small models, especially suitable for test and servicing work in the field.

Microwave equipment. The display of microwave equipment includes several types of reflex klystrons with an associated low voltage power unit and modulator unit, variable cavities, a magnetron, and a microwave wattmeter for direct measurements with an accuracy of 4%.

Elga Products Ltd., Railway Place, London, S.W.19

Water purifying apparatus. This firm will exhibit various models of their Elgastat mixed-bed deionizer for the preparation of pure water. Their conductivity meter for testing the purity of the product will also be shown.

Elliott Brothers (London) Ltd., Elstree Way, Borehamwood, Hertfordshire

Electronic systems for industrial process control. The main feature of this stand will be a large integrated system designed to show typical applications of Elliott instrumentation to a complete industrial process. The process chosen is the generation of electric power from nuclear energy produced in a graphite-moderated gas-cooled reactor similar to that at Calder Hall.

A separate section will be devoted entirely to the products of the Fisher Governor Co. Ltd. Prominent among these will be the recently introduced Series 657 pneumatic operators in the full range of sizes. These "topworks" embody several important improvements, including drawn steel casings and moulded diaphragms. (A cut-away model will be on view).

Miscellaneous instruments and components. A small general-purpose analogue-computer will be shown, and there will also be exhibits from the microwave, guided weapons, servo-components, and electrical weighing divisions.

Other exhibits. These will include the Fisher Type 430 blending unit for automatically controlling blending processes common to the chemical and petroleum industries, the Type 779K pilot for use with ball-float level controllers and using either water or compressed air as the operating fluid, and examples of special-purpose control valves recently produced by the Company.

Endecotts (Filters) Ltd., 251 Kingston Road, London, S.W.19

Test sieves. This firm will show test sieves to B.S. and U.S. standards manufactured completely from stainless steel. In addition polythene and nylon coated sieves fitted with nylon and silk weaving will be displayed.

The Endrock test sieve vibrator which will be shown can be pre-set for tests of any duration between 0 and 60 min.

Ether Ltd., Tyburn Road, Birmingham, 24

Temperature controllers. A transistor is the basis of this firm's "Transistive" Series 900 controllers which will be on show. They include a direct indicating controller, a recording controller, and a programme controller. The Transitrol incorporates a conventional galvanometer used as the measuring system, and an indicating pointer, which operates a simple photoelectric system, to produce the operative signal.

Evans Electroselenium Ltd., Potter Street, Harlow, Essex

Blood cell counter. The EEL blood cell counter to be shown will make rapid estimations with an accuracy of ±3%. In a normal blood 5 000 cells are counted in 10s.

Fluorimeter. A prototype of this new device will be demonstrated. It is designed for the measurement of adrenaline and vitamin assays, and employs two 9-stage photo-multiplier tubes in a sensitive opposition circuit.

Street lighting photometer. This is a new EEL photoelectric instrument specially developed to meet the needs of the lighting engineer. The selenium photocell is corrected for cosine error and is mounted on a universal head to allow for angular adjustment in both horizontal and vertical planes. The galvanometer scale is calibrated in four ranges, 0–0·2, 0–1, 0–5, 0–25 lumens/ft^2.

Evershed and Vignoles Ltd., Acton Lane Works, London, W.4

Analogue computer. The Evershed simple computer which will be shown is an analogue device which provides for the continuous and instantaneous solution of algebraic equations occurring in the day-to-day operation of process-control schemes and similar applications. The simple computer may be completely integrated into a process-control scheme evaluating continuously the variables and constants entering into the controlled process and its output used to maintain the process in the desired manner.

Electron hydraulic positioner. The Evershed large electro-hydraulic positioner develops a torque of up to 40 000 lb/in. and is capable of operating at a speed of 3·5 s for a full angular stroke. The operating signal required is a direct current in the range of 0–15 mA and although it may thus be operated from any suitable manually adjustable power unit, it is particularly suitable for application in conjunction with an Evershed automatic process-controller or simple analogue-computer.

W. G. Flaig and Sons Ltd., 39 Waterloo Road, London, N.W.2

Laboratory glassware and apparatus. Featured on this stand will be a representative selection of Exelo brand and Flexicon brand laboratory scientific glass-ware and apparatus. Among the newest designs are a water still, vacuum desiccator and the latest modified Scholander micrometer gas-analyser. The Flexicon range has new non-rigid interchangeable joints.

Stopcock. A new design of flat-type stopcock—the Exelo—has an interchangeable key, is robust and will not stick and has other quantities which should make this novelty of special interest.

Foster Instrument Co., Ltd., Letchworth, Hertfordshire

Internal inspection instruments. A selection of introscopes will be shown. They are used for the internal inspection of hollow parts, tubes and internal surfaces which are not normally accessible for inspection. The smallest introscope being shown will enter a ⅛ in. diameter hole to a depth of 4 in.

Temperature measuring equipment. The Company will be exhibiting a range of temperature measuring equipment which covers the entire field of temperature measurement from sub-zero up to the highest encountered in industry or research. Specializing mainly upon electrical methods of measurement the following types of instruments will be shown: resistance thermometers, for −240° C to +550° C, thermo-electric pyrometers for −200° C to +1600° C and total radiation pyrometers, for +500° C to +2000° C. All the above types will be shown as single and multi-station indicators and recorders, automatic temperature controllers, including deflectional millivoltmeter, potentiometric and electronic patterns.

Optical pyrometers for 700° C to 3000° C or higher will be shown.

Included with the above will be the Foster portable potentiometer and pyrometer tester, a new range of surface contact pyrometers and foundry pyrometers.

Foxboro-Yoxall Ltd., Lombard Road, London, S.W.19

Process control instruments. This firm will show comprehensive ranges of their process control instruments and complete systems for automatic process control. The display will present indicators, recorders, controllers, transmitters and their related sensing elements including a graphic presentation of the Consotrol series and the M/56 series of pneumatic computing relays; the 12A pneumatic temperature transmitter; the new type 13A d/p cell transmitter; electronic Dynalogs with elements; carbon electrode conductivity cells; a new magnetic flow meter; and a range of diaphragm and cylinder operated control valves.

General Electric Co., Ltd., Magnet House, Kingsway, W.C.2

Electrical measurement devices. The electrical measurement equipment will include various panel mounting instruments, hermetically sealed instruments, a number of portable instruments and a display of link testing instruments. The a.c. load analyser to be shown is arranged to give simultaneous measurement of current, potential, power, and power factor in single and polyphase circuits.

Valves. The valves on show will include representative types of transmitting valves, industrial heating valves, gas-filled and vacuum rectifiers, hydrogen thyratrons, magnetrons, audio valves, special receiving valves and various general purpose valves.

Cathode-ray tubes. Of the cathode-ray tubes to be on show the types 4GP and 6EP are new general purpose oscilloscope tubes which were developed as a compromise between high precision performance and cost. Another new tube, the VCRX410, has a travelling-wave deflection system and was developed to enable a photographic record to be obtained of high-speed phenomena occurring in a milli-microsecond or less.

Semiconductors. Semiconductor devices will include transistors for various audio-amplifier and switching applications, germanium and silicon rectifiers, and a zener diode. Of particular interest is the tube GEX 541, a germanium junction medium-power diode which can be supplied in numerous combinations of series, parallel, or series-parallel stacks to provide various output voltages and currents.

Griffin and George Ltd., Ealing Road, Alperton, Middlesex

Laboratory apparatus, instruments and equipment. This firm are specialists in the equipping of laboratories for technical instruction and industrial control and research, and it will be showing a large range of apparatus including: gas-liquid chromatographic apparatus, centrifuges, balances, anti-vibration tables, spectrometers, polarimeters, resistance boxes, furnaces, calorimeters, glassware, etc. etc.

Laboratory furniture. A range of laboratory furniture in wood and, in association with Grundy Equipment Ltd., in metal units will be on view.

J. Halden and Co. Ltd., 8 Albert Square, Manchester 2

Continuously variable reduction gear. A novel continuously variable reduction-gear called the Variodrive, was developed for use in the firm's photocopying machine, but will have many other uses. It will also be exhibited separately.

rawing office materials and equipment. The range of lucts to be shown will particularly interest the design on of the industry and will include complete drafting es, photocopying and developing machines, cartridge and ing papers and photocopying materials.

alcolite continuous photocopying machine. This machine, ch will be exhibited, has several original features.

er and Watts Ltd., 98 St. Pancras Way, Camden Road, don, N.W.1

omatic photoelectric polarimeter. In its conventional 1 the Microptic polarimeter is a visual instrument. Extinc- angles are found by matching the intensities of the seg- ts of a divided field and reading the rotation of the ol prism from a Microptic glass circle. In the form to be wn, the match point is determined photoelectrically and nown by the null reading of a meter. A digitizer cali- ed and encoded in sugar degrees, is geared to the circle. dings are taken from large illuminated figures displayed ote from the instrument, and are recorded semi-auto- ically on punched cards for later analysis in a suitable puting machine.

irect-reading attachment to the medium quartz spectro- h. An attachment will be shown with which up to ten nents can be analysed in approximately two minutes.

pectrophotometers. In the recording double-beam infra-red trophotometer (type H 800) to be shown, prism systems lass, quartz, lithium fluoride, calcium fluoride, rocksalt, issium bromide, and caesium bromide are available and interchangeable one with another or with a grating chment.

he Uvispek spectrophotometer is being shown with a tomultiplier attachment designed to increase the sensi- y of the instrument when it is used as a flame photometer. ecent development is an attachment to analyse certain tions by an atomic-absorption technique.

-ray diffraction equipment. The newly designed and greatly roved version of the Hilger Microfocus generator has a npletely clear working area measuring 30 × 36 in. The / projection above the table-top is the X-ray tube itself.

he Hilger recording diffractometer has a scanning range rom $-90°$ to $+160°$ of 2θ and several scanning speeds.

neywell-Brown Ltd., 1 Wadsworth Road, Perivale, Greenford, ldlesex

cess control and recording instruments. A wide range of ruments for use in the process industries will be shown. ong these are the following recent developments:

uplex recorder. The Duplex Electronik strip chart order has been developed to provide simultaneous measure- nts of practically any combination of two independent ables, and to record them on a single chart. The two s are entirely independent, and traverse the full 11 in. of rt width without interfering with each other. Models available with either 5½ or 2½ s full scale travel. Both asuring circuits are standardized simultaneously by means push-button, or automatically.

ligh speed recorder. The pen of this new Electronik single- ord strip chart can traverse the full 11 in. chart in ¼ s, bling rapidly changing quantities to be recorded. It has ull-balance servo-system, adaptable to the measurement practically any d.c. signal within its span limitations; sequently, it can measure any variable for which there is a able transducer to provide a d.c. signal.

A. H. Hunt (Capacitors) Ltd., Bendon Valley, Garratt Lane, London, S.W.18

Capacitors. This firm will exhibit a wide range of miniature and standard capacitors, including the following types: dry electrolytic, metallized paper, metallized film, metallized paper and film, polystyrene film, foil and paper, silvered mica, stacked mica, ceramic, and printed circuit capacitors.

Integra, Leeds and Northrup Ltd., Edgbaston House, 183 Broad Street, Birmingham, 15

Indicators, recorders and controllers. The exhibit will comprise 24 panel mounted models of Leeds and Northrup instruments manufactured in Great Britain. Other instruments being displayed will be representative examples of the Micromax mechanically balanced recording potentiometers and the Speedomax (type G) electronically operated high speed indicators and recorders. A feature of the latter is the recently introduced x-y recorders for plotting two functions; the x_1, x_2 recorder for plotting two x functions on the same co-ordinate of time, and the A.Z.A.R. recorder—adjustable zero, adjustable range—specially designed for laboratory and test use.

Kelvin and Hughes (Industrial) Ltd., 22 Caxton Street, London, S.W.1

Electronic controllers. A new range of these instruments for the control of temperature in furnaces, dye vats, heat exchangers and many other industrial applications and processes will be shown.

Flowmeters. Various types of flowmeters will be exhibited, including those for indicating, counting or recording the measurement of steam, water, thin oil, chemicals or other like fluids.

Smoke density equipment. The Mark 2 instrument to be shown is a simple, low cost, accurate and reliable means of measuring smoke emission.

Ultrasonic testing. A new system called Autosonics, whereby precise ultrasonic testing can be carried out at high speed by automatic methods, will be demonstrated.

George Kent, Ltd., Luton, Bedfordshire

Process controllers, recorders, and indicators. The theme of this firm's stand will be its Commander-class range of instruments, and the latest developments within this range. The new Commander KE electronic recorder having two speeds of operation (2 s or 15 s for full-scale travel) will be shown.

Several instruments representative of the FAF series of diaphragm-operated pressure controllers (blind setting), will be shown, these include static and differential-pressure controllers and pressure-ratio controllers for furnace-pressure, mill control, etc. They are supplied with various automatic-control functions and, if required, fitted with an overshoot-prevention device.

Low flow oil meter. The CM low-flow oil meter, of ⅜ in./½ in. nominal size for flows up to 200 g/h which will be exhibited, has several special features.

Sampling units. There will be a display of sampling units now available for the measurement of oxygen in flue gases, including a water-cooled sampling unit and a vertical heat probe unit.

Synchronous converter. This exhibit has been designed primarily for converting very small direct currents into accurately proportional a.c. signals and is used for this purpose in Kent electronic amplifiers. It is also used for the phase-sensitive rectification of small alternating currents.

Labgear (Cambridge) Ltd., Willow Place, Cambridge

Automatic chromatogram. This apparatus (type D.4129) will be exhibited working in conjunction with the printing-counter to form an automatic device for the radio-active assay of paper chromatograms.

Printing-counter and ratemeter. The exhibits will demonstrate the use of counting techniques to automation and will include the printing-counter (type D.4123) and the recording ratemeter (type D.4124). The former will count up to 100 000 counts at rates up to 3000 per second and will print out the readings. The latter will indicate and record the regular or random rate of pulses ariving at the input and furnish signals when deviation in rate is outside preset limits.

Precision timer. A crystal-controlled time source for accurate measurement in continuously running systems will be exhibited.

Laboratory Equipment (London) Ltd., Libra Works, 18–20 Dames Road, London, E.7

Hot air ovens and laboratory equipment. The firm's new range of Airflo hot air and drying ovens will be shown, and also its controlled-humidity cabinets. Another exhibit will be a heavy-duty electric-stirrer, with speeds up to 700 r.p.m.

Langley London, Ltd., Kelvin Way, Crawley, Sussex

Electrical insulation. Amongst the exhibits of this firm will be mica and micanite materials in all shapes and forms laminated plastics of paper, fabric and glass with bonds of phenol, epoxy and silicones, combination insulation and varnished cloths and tapes.

Loughborough Glass Co., Ltd., Loughborough, Leicestershire

Glassware. A display of laboratory and industrial glassware will be on view. It will include a glass water-still producing 4 l/h and plastic sleeves for use on ground-glass joints in place of grease. The industrial section will include heat exchangers and pressure-relief valves with the operating parts made of glass.

Magnetic Devices Ltd., and Power Controls Ltd., Exning Road, Newmarket, Suffolk

Relays. The series 595HS relay employing transistors will be shown; it is capable of switching loads of up to 5A at 250 V a.c. Among the range of relays shown, will be the series J.56 relay which has a contact assembly with up to eight-pole change-over. A prototype is shown of a unit of miniature solenoids giving ten solenoids per inch.

Transformers. Two types of rotary transformers will be shown, one a 2 in. type (Z.A. 42169) having a continuous output of 11 W and the other a 3 in. machine having continuous output of 60 W.

Marconi Instruments Ltd., Longacres, St. Albans, Hertfordshire

This Company will be exhibiting a wide range of telecommunications test equipment of recent design and examples of industrial X-ray apparatus. Brief details of some of the more interesting exhibits are given below.

V.H.F. test set. The test set type TF 982A has been specially designed as a compact, transportable, a.c. mains-operated instrument for the overall checking of transmitters and receivers of amplitude-modulated communication equipments, particularly of the mobile type.

Valve voltmeter. A.C. voltages between 100 μV and 300 V in the frequency range 10 c/s and 10 Mc/s can be accurately measured with this instrument.

Wave analyser operating on the heterodyne principle. The TF 455E wave analyser incorporates a double-crystal filter and has a pass band of only 4 c/s. It can be tuned to any point in the frequency range 20 c/s to 16 kc/s and gives both the absolute and relative levels of the individual components of a complex waveform.

Millett Levens (Engravers) Ltd., Stirling Corner, Barnet By-Pass, Borehamwood, Hertfordshire

Electronic equipment. The Electronics Division will be displaying various electronic units they have manufactured for the trade, among which will be v.h.f. remote control units, frequency multipliers and oscillators, match test indicators and an electronic counting device for counting units up to 30 000 per second, as well as amplifiers using the Plasma printed circuit.

Industrial Engravings. The display will show all types of industrial name-plates, and dials and scales; some of these in plastic and metal are self-adhesive.

Light engineering products. Examples of machining to fine limits will be shown.

On this stand Printed Circuits Ltd., will be displaying examples of etched circuitry as used on computers, radio, television, and record players, etc., together with these examples of circuits using a synthetic resin board copper laminate they will also be showing foil strain gauges, flexible cable forms, transducers and transformer laminations, code disks and condenser fan blades, produced by this technique.

The Morgan Crucible Co., Ltd., Battersea Church Road, London, S.W.11

The company will be displaying a selection from their range of diverse products, which are of interest to the instrument industry. A subsidiary will show their range of radio products.

Bearings and inserts. "Reservoil" sintered metal oil retaining bearings and inserts are produced by powder metallurgy techniques which result in products made to fine limits, that are self lubricating. They are available to British Standards in a wide range of sizes.

Carbon products. Among the wide range of electrical and mechanical carbon engineering components are bearings, sealing rings, piston rings, thrust washers, moulds, boats, valve anodes, pile resistors and granules.

Resistors. Morganite high-grade carbon resistors to be shown include ultra-high ohmic resistors, non-linear contact protection resistors, stable, high voltage loading resistors and e.h.t. stabilizing resistors. A full range of fixed and variable resistors, will be displayed. These include potentiometers for domestic and service applications, pre-set controls in single and banked units and fully-sealed types. Insulated and miniature resistors will also be shown.

Morganite Resistors Ltd., Bede Trading Estate, Jarrow, Co. Durham

Resistors. This firm will be showing a wide range of fixed and variable resistors. Variable resistors will include types H and LH fully sealed units, together with the miniature ed type BJ. Most of these resistors are available in able form for printed circuit application and these, too, be exhibited.

irhead and Co. Ltd., Beckenham, Kent

ctrical instruments and devices. Among a wide range indicating and measuring instruments to be shown by firm will be the following. A low-frequency phasemeter, impedance single meter, synchro-test equipment and npensated gyro-control gear, and some Weston standard s, developed for industrial use.

ow frequency phasemeter. This instrument gives direct ication of phase angle (0–360°) and differences in level dB) between two sinusoidal voltages in the frequency ge 0·5 to 10 kc/s. The measuring ranges are: impe-ice, 300 Ω to 100 kΩ (3 Ω to 500 kΩ with external resistor ndard), angle ±90°. Its uses include the impedance l phase characteristics of electro-mechanical transducers l active networks, percentage deviation of a test component n a standard having approximately the same phase angle, voltage (0–100 mV) the impedance of electrolytic capacitor l as a phasemeter (0–360° ± 5%).

lder Bros. and Thompson Ltd., Dalston Lane Works, ndon, E.8

th proving switch. An earth proving supply point switch be demonstrated, for use with portable electric tools, feature being that the tool cannot be energized unless earth lead from the supply point to the tool is intact.

ndicating electrical instruments. A wide range of indicating ruments will be shown with segmental and circular scale racteristics from 1–30 in. diameter. In one instrument internal electromagnetic locking device enables the instru-nt deflexion to be locked at any desired instant, and to be d at leisure.

Recording instruments. A range of graphic chart recording ruments for electrical quantities will be exhibited.

Relays. Among a range of relays to be shown will be a ivative relay in which a moving coil element is coupled a light contact system in such a manner that contact ration depends upon the angular velocity of the moving . The relay can therefore be used to provide an alarm initiate corrective action when the rate of rise or fall of rent in a circuit exceeds a preset level.

h and Thompson Ltd., Oakcroft Road, Chessington, Surrey

istance-capacitance comparison bridge. This new Nashton rument is intended for the measurement of resistance -500 MΩ and capacitance (5 pF to 500 μF) or for the nparison of resistors, capacitors or inductors against wn standards. It employs the Wheatstone bridge for stance measurement and comparison, and the de Sauty lge for capacitor measurement and comparison; the isurements are made at mains frequency and at 18 V. A el twin neon device is used to indicate the balance point.

alve-voltmeters. The valve-voltmeters to be shown ude one which has scales of from 0–10 mV and 0–300 V; ther has six a.c. ranges from 1 V to 300 V full-scale ection and seven d.c. ranges from 1 V to 1000 V full-scale ection.

ther exhibits. These will include: aeration test burner, I.F. coating thickness meter, computor unit, d.c. amplifier, trolytic polisher, electronic colloid osmometer, flow trolled switches, mains pressure tester, metallurgical unting press, micro-hardness tester, pressure controlled switches, Reid vapour pressure apparatus and recorder, shorted turn detector soil resistance meters, vapour liquid ratio apparatus.

Negretti and Zambra Ltd., 122 Regent Street, London, W.1

Automatic controllers. Three models will be shown from the range of two- and three-term controllers which are free from interaction between terms, and so generate a true basic control response. Other exhibits in this group will be a pyrometer controller for temperature up to 1600° C, and dial pressurestat designed to make or break an electrical circuit with a rise in pressure to a certain value; a humidity controller, an air-operated programme controller, and time/temperature recorder controllers.

Humidity measuring instruments. A number of hygrometers of the indicating, recording and controlling types will be shown.

Pressure measuring instruments. A servo-operated pressure recorder which will be in operation demonstrates the measurement of pressures down to 0·2 w.g. by means of various gauges and recorders. Pitot tubes, and U-tube liquid gauges for measurement of pressure or suction will also be exhibited.

Temperature measuring instruments. Instruments to be shown for the measurement of temperatures over a very wide range include thermo-electric pyrometers, electrical resistance recording thermometers, mercury-in-steel indicating and recording thermometers and mercury-in-glass thermometers.

Other instruments. A range of meteorological instruments will be shown, as well as a number of aeronautical instruments.

C. A. Norgren Ltd., Shipston-on-Stour, Warwickshire

Compressed air equipment. The range of compressed air equipment to be exhibited includes air filters of the manual and automatic drain type, and air purifiers; pressure regulators, for the $\frac{3}{4}$ in. and 1 in. B.S.P. sizes. The Norgren compressed air line lubricators; the Spray-Lube and Mist-cool systems of cutting tool lubrication, and level control switches designed primarily for indicating level in Norgren lubricators, but suitable for low or high level indication in a wide variety of applications.

L. Oertling Ltd., Cray Valley Road, St. Mary Cray, Kent

Balances. A range of new and improved single and double pan balances will be shown. These employ new materials and have many novel features. A typical example is the Model HO1 which has push-bar operated Releas-o-matic grouped controls and weight totalizer. The sensitivity is 0·1 mg/$\frac{1}{2}$ div, and weight loading 200 g.

Philips Electrical Ltd., Century House, Shaftesbury Avenue, W.C.2

5 *MeV linear accelerator* (photographic display). So as to allow greater manœuvrability, this equipment is mounted on a motor-driven overhead gantry. Although this machine has an X-ray output capable of penetrating steel up to 10 in. in thickness, it is characterized by a remarkably high degree of radiographic sharpness, the effective focal spot being only 2 mm. This is achieved by means of a crossed cylindrical lens system. In this way the electron beam is focused on a very small area of the target. An example of the lens assembly with its coils and pole pieces forms part of the exhibit. The electron gun assembly for this type of linear accelerator, together with a sample of corrugated wave-guide and a so-called "door knob" feed, are also shown.

Nuclear energy instruments. The firm's hand and clothing monitor for checking after working with radio-active materials will be shown. A pulse analyser, a fast scaler, and a set for routine testing of spurious pulses produced within nuclear counters will be among the exhibits.

Potentiometric recorders. A wide range of potentiometric recorders will be shown, adapted for various purposes.

Pilkington Brothers Ltd., St. Helens, Lancashire

Protective glass for nuclear research. Heavy lead glass shielding blocks and protective glass in polished plate form, for use in nuclear research will be exhibited. This glass also has high-voltage medical and industrial X-ray applications.

Other exhibits. Čerenkov blocks of high density glass for gamma-ray spectroscopy, optical glass for the scientific instrument industry, disks for the manufacture of windows for wind tunnels, low expansion disks for optical mirrors, glass for the face plates of electronic tubes and microscope cover slips and slides will be other exhibits.

There will be a range of eye-protective glasses for ophthalmic purposes and for welding, optical colour filter glasses, samples of precision bore glass tubing and all-glass interchangeable syringes, designed to simplify hospital sterilization systems.

W. R. Prior and Co., Ltd., Northgate End, Bishop's Stortford, Hertfordshire

Microscopes. A range of microscopes for use both in research and industry including stereoscopic binocular microscopes will be shown.

Micro manipulator. In the instrument to be used in conjunction with the low power stereoscopic microscopes, one complete revolution of the control equals 0·152 mm. The head is fitted with two-way horizontal movement, providing forward and transverse travel, each carrying a vernier scale to read 0·1 mm.

Racal Engineering Ltd., Western Road, Bracknell, Berkshire

Digital units. Among the digital units to be shown will be a counting unit for counting up to 100 kc/s, a frequency meter for the range 10 c/s to 30 Mc/s and another for the range 10 c/s to 1 Mc/s sine wave and pulse with an accuracy of 1 part in 10^6. A range of plug-in digital counting units has been developed and will be on show. The stabilized power unit to be exhibited is designed to be built in experimental or production equipment. The Racal microsecond chronometer to be shown measures the time intervals with an accuracy of ±1 μs in the range 3 μs to 1 s and with a 6 digit mechanical register up to about 100 h.

Radiovisor Parent Ltd., Stanhope Works, High Path, London, S.W.19

Photoelectric devices. Two types of smoke detection equipment for use in boiler houses and similar plants, will be exhibited.

The Flamestat series of Radiovisor flame failure protection equipment for the oil and gas burning industries will be shown.

The Savelite transportable photoelectric unit is intended to assist fuel watchers to prevent wasteful use of interior lighting. The unit is set to a predetermined light level at which its relay operates an alarm.

Numerous other ingenious applications of photocell devices for counting, batching and controlling will be shown.

Recorder Charts Ltd., Clyde Vale, Dartmouth Road, London, S.E.23

Recorder charts. A wide range of charts produced for leading instrument manufacturers will be shown.

The exhibit will indicate the specialized service which is offered for precision charts. Charts for conventional ink recording are produced on special high-stability papers which ensure minimum expansion or contraction through varying degrees of humidity. In addition there have been some interesting developments recently in the field of inkless recording with heat, pressure or electric current as the recording medium.

Rotameter Manufacturing Co. Ltd., 330 Purley Way, Croydon, Surrey

Continuous-weighing density meter. The R.M. continuous weighing density meter for liquids and slurries will be demonstrated as a working model.

Flowmeters. Included in the display of Rotameter flowmeters will be the metric series, based on interchangeable tubes and floats, which has been extended to cover flowmeter applications on nearly all liquids and gases.

A number of Rotameters built for special duties will be shown and these include a working demonstration of flow ratio control by pneumatic method.

Liquid level indicator. The Ekstrom liquid level indicator fitted with the magnetic-coupled limit switches now available will be shown working.

The Royal Sovereign Pencil Co. Ltd., 54 Neasden Lane, London, N.W.10

Special pencils. Royal Sovereign Ferroprint pencils will be shown; they have light-stopping properties, which enable photoprints to be made directly from pencil drawings. Ferroprint refill leads in degrees 9H–2B, each lead stamped with its degree-marking, are a new feature of this series.

Examples of the Royal Sovereign Chinagraph for marking on glass, metal and all polished surfaces will also be on show.

The new Royal Sovereign press button lead holder which contains leads 1·80–2·1 mm in diameter, will be of special interest.

W. H. Sanders (Electronics) Ltd., Gunnels Wood Road, Stevenage, Hertfordshire

Magnetic amplifiers, transistors and magnetic amplifier cabinet. A range of encapsulated transductors and rack-mounted magnetic amplifier chassis, for use in automatic control systems will be exhibited. Also on show will be a cabinet containing a number of various magnetic amplifier chassis as used in the automatic control of industrial processes.

Microwave analytical test equipment. A complete range of newly developed microwave test equipment in waveguide size 18 covering 12·4 to 18·0 kMc/s (J Band). Items in the range include, a precision standing wave meter, a high directivity Riblett and Sard type multi-hole directional coupler, a high Q-wave meter covering 11·5 to 18·0 kMc/s and a precision calibrated glass vane attenuator. A complete range of microwave test equipment and components in waveguide size 16, 8·2 to 11·5 kMc/s (X Band), will be shown, including a number of newly developed instruments.

ther exhibits. Signal generators, oscilloscopes, relays, a spot welding controller will be other exhibits Stevenage ays Ltd. will show.

age and Parsons Ltd., Watford By-Pass, Watford, Hertford-e

orders. The display will include a six-channel recording nera, providing a continuous and simultaneous record 120 mm sensitized paper and a pen recorder which will ord simultaneous and continuous ink traces on 240 mm 00 c/s.

emote handling equipment. The new remote handling ipment to be shown which has been developed in collabo-on with the A.E.R.E., Harwell, includes master slave nipulators for handling highly radioactive or toxic terials through protective screens or walls several feet k. A range of handling tools and devices will also be oduced which will carry out operations similar to the ster slave manipulator but are designed for working ough thinner walls or screens. A wide range of auto-tically removable tool heads are available for any required ration—heating, holding, weighing, sealing, cutting, -opening, etc.

esistance thermometers. A range of commercial resistance rmometers will be shown. The accuracy of these battery rated platinum thermometers is given as ±1° C, and the sitivity as ±1° C. Six models are available to cover the perature range from −50 to 250° C.

hielding. A series of lead bricks and shielding lead pots be exhibited.

train recorder. A static strain recorder will also be wn, which provides for the measurement of strain at up to points, with three interchangeable degrees of sensitivity. maximum sensitivity, the instrument will record strain nges down to 2½ μ in./in. Modified equipment for use on ber or other materials with a low modulus of elasticity can be supplied.

vis Recorders Ltd., 19 London Road, Gloucester

orders. A recorder will be shown which has been designed meet the demand for smoke control apparatus. It shows exact time and for how long the warning apparatus was rating.

mechanically operated recorder will also be shown fitted a centralized lubrication system to give an independent ck on the times of lubrication. Other examples from the n's range of nearly a hundred different models and types l be exhibited.

vomex Controls Ltd., Crowborough Hill, Jarvis Brook, ssex

. voltage regulator. A regulator rated at 3–30 V, 0 A with a ripple voltage at full load not exceeding % r.m.s. will be on show in which the smoothing has n achieved in a novel way.

ow frequency waveform generator. The l.f. waveform nerator (type LF 51) has been designed for testing auto-tic control systems. In the case of electric systems it can used directly, and for pneumatic systems suitable electro-eumatic convertors are available. The range extends from ycle every 33 minutes, up to a fast test signal pulse of μs duration.

Short Brothers and Harland Ltd., Castlereagh, Belfast

Analogue computer. This firm's main exhibit will be an analogue computer which incorporates many new and exclusive features, produces its results graphically either as traces on a cathode-ray tube or plotted on a paper chart. It is of simple construction and layout and can be handled by an operator having no specialized electronic knowledge. All units are arranged to slide quickly and easily into the framework of the console and can be readily changed as necessary for the solution of different problems. A selection of the various computing units is to be shown separately.

Rocking table. A two-axis servo-controlled rocking table, designed by the company for development work on gyro-control systems and for their functional testing will be shown.

Servo-mechanisms. Electro-hydraulic servo-mechanisms, of the type now being intensively developed by the Company, together with a range of high pressure hydraulic components designed specifically to meet industrial requirements, will be exhibited.

Siemens-Edison-Swan Co. Ltd., 38–39 Upper Thames Street, London, E.C.4

Amplifier. The Test-bed amplifier, designed for intercommunication regardless of extreme noise will be shown.

Electronic equipment. Electronic control and indication equipment is represented by a model electro-mechanical indicator suitable for displaying information to a number of people. The information may be in the form of bus, train or aircraft arrival-departure details, staff location display or advertising information, etc.

A full range of industrial and radio valves is supported by transistor exhibits.

A number of cathode-ray tubes to be on show demonstrate the latest techniques and advances; other exhibits consist of stabilized power units, special oscillators, physiological amplifiers and recorders.

Telephone apparatus. The exhibits will include loudspeaking telephones, a "transistorized" telephone for deaf people, a personal paging staff location system, and various associated equipment.

Smiths Industrial Instruments Ltd., Chronos Works, North Circular Road, London, N.W.2

Relay. The calibrated relay to be shown has an accuracy of ±1%, under static conditions. It has three other features, which are a very low power input, a high contact pressure, 15 to 60 g, and contact wear does not affect the accuracy of setting.

Tachometer generator. The series M generator is an all-purpose heavy duty tachometer generator for remote indication of rotational speeds. It has been specially developed to meet the demand for a robust, waterproof, long-life unit having physical dimensions for a very wide range of speeds and duties. Generators of this class are available for ranges varying between 0–500 r.p.m. and 0–6000 r.p.m.

Other instruments. Also on show will be a range of tachometers, electrical and mechanical counters, escapements and gauge mechanisms, hobs and cutters, and constant speed motors.

The Sperry Gyroscope Co. Ltd., Great West Road, Brentford, Middlesex

Equipment for process control and other servo applications. The exhibits will comprise a range of electrical, electronic, mechanical and hydraulic servo components for process control, automatic machine tool and many other servo applications. They will illustrate, by typical representative examples, how Sperry components, techniques and experiences can be applied.

Gears. Examples of precision gear cutting will be on show.

Southern Instruments (Oscillograph Division), Frimley Road, Camberley, Surrey

Resistance pressure gauge. The type G289 flat-tube resistance pressure gauge is based on a design evolved by the Royal Aircraft Establishment. A transducer measures pressure applied to the inside of a flat-sided tube, sealed at one end. Electrical resistance strain gauge windings bonded to the outside of the tube detect the bending strains on the tube.

Universal oscillograph. The type MUR6 cathode-ray oscillograph has been developed to provide a multichannel recording equipment of great flexibility. The 3 in. diameter recording tubes are used and the focusing system enables full coverage of 70 or 120 mm paper to be obtained and the traces are brought on to a common time line. Up to twelve channels, with a separate tube for time marking, can be accommodated.

Other exhibits. This Division will also show the firms six-channel pen recorder, its auto-developer for processing oscillograph paper records in daylight, and its torsional vibration pick-up.

Standard Telephones and Cables Ltd., Connaught House, Aldwych, London, W.C.2

Electronic digital computer. The principal exhibit on this stand will be the Stantec Zebra electronic digital computer which is a general purpose computer of medium size and speed. It is suitable for carrying out a large variety of the information processing problems required to be solved in research establishments and in industrial and commercial organizations generally. The version of Stantec Zebra to be shown (including input and output equipment) is primarily a mathematical machine.

Electronic equipment. A range of components and devices appropriate to the instrument, electronic and automation industries, including semi-conductors, etc., will also be shown.

Endless loop magnetic tape storage machine. This machine provides an infinitely extensible method of magnetic storage of information with a low random access time to any of the information. Magnetic tape in an endless loop passes between a rotor and a stator and under a magnetic head assembly. Stator and rotor are provided with compressed air and vacuum under the control of a special high-speed valve. Motion of the tape is started and stopped at high-speed by moving it between stator and rotor, each using air pressure and suction alternately. Tape loops, up to 300 ft. in length, are carried in narrow flat containers which form a jack-in unit, all the capstan drive and magnetic head electrical and air connections being on jack-in plugs and sockets. Ten such units can be accommodated in a single frame mounting.

Sunvic Controls Ltd., 10 Essex Street, Strand, London, W.C.2

Process control instruments. A wide range of Nullmatic instruments and controllers for industrial use will be shown. A new accessory provides for continuous indication of valve pressure, and permits the operator to check deviation of the variables by quickly scanning the control board. A universal manifold block permits the mounting of any "plug-in" Nullmatic controller, and makes for maximum adaptability.

Taylor-Short and Mason Ltd., Hale End Road, London, E.17

Process controllers and recorders. This firm will display its range of miniature indicators and recorders of the Transet series, and of its pneumatically operated Fullscope instruments. Among recent developments will be the Taylor Transverter-Transmitter, for measuring linear flow, and dependent quantities, the 65 K Transet receiving flow integrator, a compact unit for recording the total flow in a system, and the Transet Fulscope controller which is of the position balance type and supplements the firm's force balance miniature controller. A prototype potentiometer-transmitter for use with thermocouples will be shown; the signal can be converted to a pneumatic one, if required.

The Telegraph Condenser Co. Ltd., North Acton, London, W.3

Capacitors. New ranges of P.T.F.E. dielectric capacitors for use up to 200° C will be exhibited, together with miniature tantalum and low leakage electrolytic capacitors. Metallized polystyrene capacitors for tuned filter circuits will also be shown.

Printed circuits. A wide variety of printed circuits will be displayed and in association with it, capacitors for direct assembly into the panels.

The Thermal Syndicate Ltd., Wallsend, Northumberland

Ceramic products and laboratory ware. Sinconia and thoria laboratory ware products for use up to 2400 and 3200° C respectively will be shown, as well as many examples of the firm's laboratory ware, including electric immersion heaters and mercury vapour lamps.

Quartz products. To meet the present demand for really high purity fused quartz in which to produce hyper-pure silicon, transparent Vitreosil HPQ crucibles, thin-walled furnace boats, supporting jigs and tubes are now available. Transparent Vitreosil can now be supplied precision ground on the external surface to an accuracy of $\pm 0{\cdot}0005$ in. for instruments requiring stable electrical windings, and examples will be shown. Platinised fused quartz wool of 6 μ thread diameter, will be shown in two forms: one with 3% platinum content and the other with 5% platinum, for use up to 900 to 950° C.

The Tintometer Ltd., The Colour Laboratory, Waterloo Road, Salisbury, Wiltshire

Colour measuring instruments. Two new instruments will be shown as well as additions to the firm's range of colour standards including those for the estimation of humidity with cobalt thiocyanate papers. The Lovibond Schofield tintometer (Type 2), is a visual colour measuring instrument based upon the Lovibond permanent glass series of subtractive primaries red, yellow and blue; *The Lovibond portable hand tintometer*, also being shown, was originally designed for measuring the colour of skin.

J. W. Towers and Co., Ltd., Victoria House, Widnes, Lancashire

Automatic standard distillation apparatus. The apparatus to be exhibited is a development of the Towers automatic distillation apparatus, which was exhibited two years ago.

Countercurrent analysis apparatus. This Gilson–Wright pattern apparatus is made in semi-automatic and fully-automatic models and is for carrying out the technique of countercurrent distribution between two liquid phases, as an aid in synthetic and analytical chemistry.

Scientific laboratory apparatus. A wide range of laboratory apparatus will be exhibited.

son and Mercer Ltd., Croydon, Surrey

ostat. An all-welded Perspex construction is used for bath with double walls trapping dried air. The system peration gives accurate control from room temperature n to −20° C, utilizing some of the range of refrigerator s which will also be on show.

boratory apparatus. A wide range of laboratory apparatus etal and glass, will be shown and a number of novel bits. These cover a wide field, from which only a few be mentioned here.

vens. A large double entry vacuum oven with thermoc control has been developed from the smaller one which also be shown. This will operate up to 120° C and zes some neat metal and rubber vacuum taps. A new of high temperature oven is in stainless steel, with direct ant heat elements operating up to 450° C.

astic diaphragm tap. A new type of plastic tap utilizing aphragm and suitable for use in glass or metal apparatus ing shown.

hermostat baths. The S.200 series IV thermostat bath s a sustained accuracy better than ±0·001° C and can perated up to 120° C with oil. Another thermostat bath s accuracies of ±0·05° C at temperatures down to −70° C operates on a special system utilizing a heat exchanger h will operate satisfactorily from −20° C or higher t down to −90° C if necessary.

ald Trist & Co. Ltd., Bath Road, Slough, Buckinghamshire

strial smoke density equipment. The smoke alarm e A.S.B.) gives warning that smoke emitted from a mney has exceeded a predetermined limit.

vel control equipment. A range of Morrey magnetic switches, constructed in various materials, will be on . These switches are now available for working pressures o 3000 lb/in^2 and working temperatures up to 400° C se in almost any liquid.

eam raising boiler equipment. The latest addition to an nsive range of level alarm equipment will be featured. is one of a series of vertically mounted electric high and level alarms now available for steam boiler applications o 450 lb/in^2 working pressure.

st Turner Electrical Instruments Ltd., Chiltern Works, Wycombe, Buckinghamshire

trical indicating instruments. The display of electrical suring instruments developed and produced by this firm include a range of rectangular instruments designed to greater clarity of reading by virtue of lengthened scales.

ash units. A comprehensive range of electronic flash s suitable for commercial, laboratory, repetition and io photography in both colour and black and white form part of the exhibit, including the Model 1000/1 dflash with energy of 100 J. Equipment will be shown two lamps by the aid of which two extremely short sures, separated by an adjustable and precisely determined val of a few microseconds can be made on one conional negative.

tentiometer. A portable 1V potentiometer designed in unction with the British Post Office for work in cathodic ection will be shown.

roboscopes. Among the wide range of stroboscopes to hown are models to cover every possible application, visual and photographic with repetition rates up to flashes per second and at lower rates with an energy to 60 J per flash.

Unicam Instruments Ltd., Arbury Works, Cambridge

Spectrophotometers. The Unicam SP500 spectrophotometer for ultraviolet and visible absorption measurements combining the highest accuracy and precision with reliability and easy operation will be shown together with a range of accessories. The Unicam SP600 spectrophotometer for the visible range has the versatility of a colorimeter and is equally suited to the research laboratory and to routine control. The SP100 double-beam infrared spectrometer to be exhibited offers fully automatic operation with recording facilities.

X-ray crystallographic apparatus. A range of cameras and goniometers for all normal techniques in X-ray crystallography including high temperature work will be shown.

United Trade Press Ltd., 9 Gough Square, Fleet Street, London, E.C.4

Specimen copies of *Instrument Practice* a monthly journal covering the whole field of instrument technology and instrumentation will be on show, and *The Instrument Directory and Buyers Guide* which refers to all the principal manufacturers and suppliers of scientific and industrial instruments and their component parts in this country. These publishers will also show their *Course in Industrial Instrument Technology* by J. T. Miller and the second edition of *The Instrument Manual.*

The Wayne Kerr Laboratories Ltd., Roebuck Road, Chessington, Surrey

Electrical and Electronic Instruments. Two bridges based on the transformer ratio arm principle which have been developed by this firm will be exhibited.

Other new instruments to be exhibited are an X-band oscillator with a frequency range of 8500 to 10,000 Mc/s and power output of 15–35 mW constant to 2 dB, a double vane microwave wattmeter for the range 10–100 W, a video noise level meter with a bandwidth of 10 kc/s to 10 Mc/s an audio oscillator covering the range 10 c/s to 100 kc/s and a range of wavemeters covering 2000–40 000 Mc/s.

West Instruments Ltd., 52, Regent Street, Brighton, 1, Sussex

Indicating pyrometers. A range of West indicating pyrometers will be on view.

Recorder. The Model M. Marksman strip chart potentiometer recorder will be shown; the amplifier uses printed circuits and transistors, for which a number of advantages are claimed.

Temperature controllers. The complete range of Gardman controllers, will be shown. In their operation these pyrometric controllers employ an indicating system actuated by a thermocouple and a relay system governs the supply of fuel or power as required to maintain the temperature desired.

Williams and James (Engineers) Ltd., Chequers Bridge, Glos.

Compressor and valves. A range of compressors and valves will be exhibited, including an oil free compressor with a 4 in. stroke and a piston diameter of 5 in. The models available are single, twin and four cylinder capable of a free air delivery up to 100 ft^3/min at 60 lb/in.^{2} on continuous duty and 80 lb/in^2 on intermittent duty. A range of stainless-steel bodied valves will be one of the new developments on show.

Pressure regulators. The W. and J. Pneumerstat pressure regulators which are being exhibited will be of special interest to scientific instrument users who require steady air pressures for measurement or other purposes.

Notes and comments

Zeitschrift für Instrumentenkunde

After a lapse of 13 years, caused by the war, the German *Zeitschrift für Instrumentenkunde* has made its reappearance. The new issue which opens the 65th volume appears almost exactly 75 years after its first publication in 1881. At that time the new journal was the first of its kind in the world to deal with the description of scientific instruments and it became the model for journals such as our own in other countries. Professors Glazebrook and J. J. Thomson cited the *Zeitschrift für Instrumentenkunde* as an example when in the 1920's they promoted the founding of our *Journal.*

The *Zeitschrift für Instrumentenkunde* was purposely designed to forge a link between the academic centres of scientific study and the fast growing industry in the new German Reich. In its volumes the growth of German technology and instrument making can be traced. The first article ever published in the journal describes a barometer and is signed by Mechaniker R. Fuess, who in the years to come gave his name to one of the most important German instrument firms. In spite of the old spelling with c's instead of z's or k's, and with h's which have long since disappeared from behind t's, the foreign reader will still find the back numbers of the *Zeitschrift für Instrumentenkunde* pleasant reading. It is to be feared that he may not have such an easy passage with the neo-German of the most recent issue using words like *Feinwerk* which the reader may have difficulty in finding in a dictionary. We suggest that the Editors consider retaining the more conservative style of the old volumes. We welcome the reappearance of the *Zeitschrift* and wish the Editors (Prof. Dr. W. Keil of Stuttgart and Reg.-Rat Dr.-Ing. H. J. Schrader of Braunschweig) and the publishers (Friedr. Vieweg & Sohn of Braunschweig) all success in their venture.

British Institution of Radio Engineers' Convention

"Electronics in Automation" is the theme of the British Institution of Radio Engineers Convention to be held in the University of Cambridge, from June 27–July 1.

Approximately thirty papers are being presented to cover the six sessions which are, Office Machinery and Information Processing; Machine Tool Control; Chemical and Other Processes; Simulators; Automation in the Electronics Industry; Automatic Measurement and Inspection. The papers will be read and discussed in the Clerk Maxwell and Green Lecture Theatres of the Cavendish Laboratory. Further information may be obtained from the Institution's Offices, 9 Bedford Square, London, W.C.1.

World Directory of Crystallographers

The International Union of Crystallography is considering the possibility of preparing a world directory of crystallographers. This list would contain the names and addresse of all practising crystallographers, including advance graduate students. It is planned to compile a preliminar list in time for the Fourth General Assembly to be held i Montreal, July 10–17, 1957. The Secretaries of the nationa committees (*Acta Cryst.*, **8**, 857, 1955) have been asked t prepare a list of crystallographers in their countries. Som scientists and technologists, however, who carry on crystallographic work (including X-ray, electron or neutron diffractio and microscopy or other techniques) are not members o scientific societies having a unique crystallographic interest and might therefore be missed. Those who come into thi category are asked to send their names and addresses, i printed letters, to Dr. Williams Parrish, Philips Laboratorie Irvington-on-Hudson, New York, U.S.A.

Conversion factors for specific energy, energy and pressure

Mr. E. J. Le Fevre of the Mechanical Engineering Researc Laboratory of the Department of Scientific and Industri Research, has prepared a report giving the conversion facto resulting from recent international decisions regarding uni and kindred matters that affect tables of thermodynam properties of steam and other working media.

Interconversion tables for specific energy, energy an pressure are given. Copies of this six-page duplicated repo are obtainable gratis from the Director, Mechanical Eng eering Research Laboratory, East Kilbride, Glasgo Applications should quote HEAT NO. 111.

British Journal of Applied Physics

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A high speed electronic analogue field mapper

By R. B. Burtt, M.Sc.Tech., Grad.I.E.E.,* and J. Willis, B.Sc.(Eng.), A.M.I.E.E., Electrical Engineering Department, Manchester College of Science and Technology

[*Paper first received* 31 *August, and in final form* 27 *November*, 1956]

The paper describes an experimental high speed field mapper that was built to demonstrate the feasibility of a purely electronic mapping technique. A complete field is mapped in a twenty-fifth of a second and continuous repetition gives the effect of a moving picture. An elementary phosphor potential stabilization theory is discussed, some of the conclusions of which were verified by experiment. The construction of the mapper is briefly described and some of the field maps are reproduced.

mapping of electrolytic analogue fields by conventional ıods is necessarily tedious and attempts have been made ̇reen, Mickelsen, Pickering$^{(1-3)}$ and others to reduce the involved, by the use of electronic detectors that auto-cally record equipotentials as a probe is moved in the rolytic tank. The pantograph, which is usually a mecha- linkage, perhaps servo-driven, still limits the speed of ation.

ıe instrument described in this paper maps a complete of equipotential lines in one twenty-fifth of a second by electronic principles throughout. The map is repeatedly ayed on the screen of a cathode-ray tube so as to give effect of a moving picture and to allow field maps to be rved while the analogue boundaries are being adjusted.

g. 1 is a block diagram of the mapper. The analogue was built on the end of a cathode-ray tube so that the screen formed the bottom of the tank. When a high uency alternating potential was applied to the electrolytic ogue an alternating current was superimposed on the dy secondary emission current returning to the final le of the tube. This current was proportional to the ntial appearing just over the spot, and was of sufficient nitude to allow easy detection and amplification. The was deflected so as to trace out a raster of just over lines in synchronism with a display oscilloscope. After lification, the signal was divided up by triggers which pulses at equipotential values on to the grid of the display to show a series of equipotential lines.

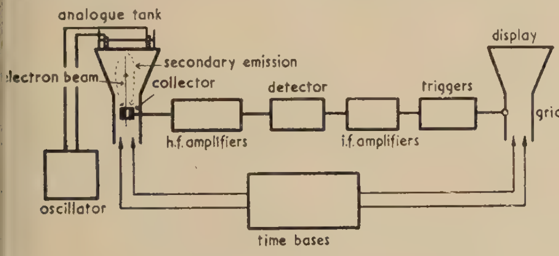

Fig. 1. A block diagram of the mapper

E MEASUREMENT OF ANALOGUE POTENTIALS

ıe measurement of potentials by means of a cathode-ray spot relies on the stabilization of the phosphor potential at the spot$^{(4,5)}$ as a result of the energy distribution of the electrons leaving the phosphor as secondary emission [Fig. 2(*a*)].

A positive potential of the phosphor will tend to re-attract a proportion of the secondary emission back to itself, whereas a negative potential will have the opposite effect. If, therefore, the phosphor surface is struck by a beam of electrons, the apparent secondary emission will be dependent on the potential of the phosphor itself.

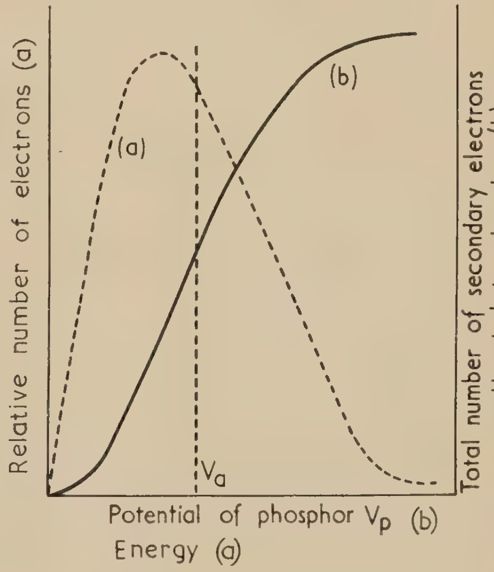

Fig. 2. Secondary emission characteristic of the phosphor

Fig. 2(*a*) can be re-arranged to show the number of secondary electrons re-attracted to the spot for every volt difference between the phosphor at the spot and the internal graphite coating of the tube, see Fig. 2(*b*). When this characteristic is inverted it shows the connexion between the apparent secondary emission ratio of the phosphor and the phosphor potential, see Fig, 3(*c*).

Under steady state conditions the phosphor potential must be such that the difference between the current lost by secondary emission and that received from the electron beam equals the leakage current from the phosphor to the nearest electrode in the tube (usually the internal graphite coating). The phosphor potential V_p under these conditions is equal

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Now at Department of Electrical Engineering, University of rpool.

to $V_a - i_l R_l$, where V_a is the graphite potential and i_l and R_l the leakage current and resistance respectively.

Therefore,
$$V_p = V_a - R_l(i\delta - i)$$
$$= V_a + R_l i(1 - \delta),$$

where i is the beam current and δ the secondary emission ratio. A straight line d can thus be drawn in Fig. 3 which cuts the $\delta = 1$ axis at $V_p = V_a$. The phosphor potential will stabilize at the intersection p, which has been shown by Litting(6) to lie in the region of 2–4 V positive with respect to the rest of the screen, which is itself some 10–30 V negative with respect to the internal graphite coating.

A positive potential applied to the outside of the tube screen will raise the potential of the spot momentarily by an equal amount. This will have the effect of moving the working point in Fig. 3 to the point x. The apparent secondary emission ratio of the phosphor will be reduced, whereas the leakage current will remain relatively small. The excess of current now reaching the spot over that leaving it will charge up the phosphor until its potential drops once more to the stabilized potential at p. As long as the characteristic is a straight line in the region of the stabilized potential, the charging current will be proportional to the difference between the spot potential and its stabilized potential and will decay exponentially. A negative applied potential will move the working point in the opposite direction and a negative charging current will flow to the spot. A transient current thus flows to or from the phosphor which, if the characteristic in Fig. 3 is linear, is proportional to the potential applied to the outside of the screen. This current can be conveniently detected by measuring the changes in the secondary emission current flowing to the final anode of the tube.

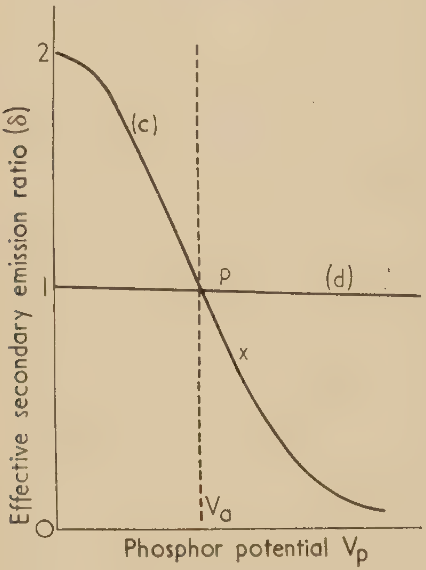


Fig. 3. Equilibrium conditions at the spot

Since this action is of a purely transient nature, once the beam has scanned along a line on the phosphor no repetition of the process can occur until the stabilizing charges have had time to leak away. High speed repetitive measurement of steady potentials applied to the outside of the screen were, in fact, prevented by the slow time constant of the phosphor charge leakage, and alternating potentials had to be used in the analogue tank.

The transient spot charging current i_c will be equal to t beam current i less the current lost by secondary emissi and leakage, i_2 and i_l respectively.

Now $i_2 = \delta i$, where δ is the apparent secondary emissi ratio, and, since δ is controlled by the characteristic Fig. 3,
$$i_2 = i[1 - k(V_p - V_a)]$$
where k connects δ with V_p and is constant as long as Fig is a straight line near $V_p = V_a$.

Therefore $i_c = i[1 - 1 + k(V_p - V_a)] - i_l$

But $V_p = V_a + e - q/c$, where e is the difference betwe the potential applied outside the screen and V_a. q/c is t potential to which the capacitance c between the spot and t conductor applying the potential e is charged by the beam.

Therefore $i_c = ik(e - q/c) - (e - q/c)/R_l$,

since $i_l = (V_p - V_a)/R_l$

since $i_c = dq/dt$
$$dq/dt + ikq/c = i(ke) - (e - q/c)/R_l$$

If, so as to simplify the expressions, the leakage current neglected, the expression becomes, with an alternating appli potential,
$$dq/dt + ikq/c = i(ke \sin \omega t)$$

Using the Laplace transformation
$$\bar{q}(p + ik/c) = ike\omega/(p^2 + \omega^2)$$
Therefore $\bar{q} = ike\omega/(p + ik/c)(p^2 + \omega^2)$

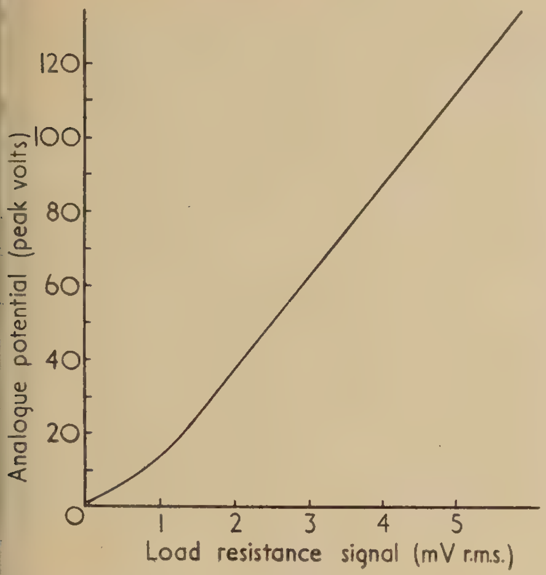
and resolving into partial fractions,
$$\bar{q} = \frac{ike\omega c^2}{c^2\omega^2 + i^2k^2}\left(\frac{1}{p + ik/c} - \frac{p}{p^2 + \omega^2} + \frac{ik}{c} \cdot \frac{1}{p^2 + \omega^2}\right)$$

Therefore
$$q = \frac{ike\omega c^2}{c^2\omega^2 + i^2k^2}\left[\exp(-ikt/c) - \cos \omega t + \frac{ik}{c\omega} \sin \omega t\right]$$
$$= \frac{ike\omega c^2}{c^2\omega^2 + i^2k^2}\left[\exp(-ikt/c) - \right.$$
$$\left. - \frac{(i^2k^2 - \omega^2c^2)^{\frac{1}{2}}}{\omega c} \cdot \sin(\omega t + \tan^{-1}\omega c/ik\right.$$

Therefore
$$i_c = \frac{i^2k^2e\omega^2c}{c^2\omega^2 + i^2k^2}\left[\exp(-ikt/c) - \right.$$
$$\left. - \frac{(i^2k^2 - \omega^2c^2)^{\frac{1}{2}}}{\omega c} \cdot \cos(\omega t + \tan^{-1}\omega c/ik\right.$$

The transient component of the charging current, whi decays extremely rapidly, can be neglected as steady st signals are those normally observed. The amplitude of carrier is equal to $e\omega cik/(c^2\omega^2 + i^2k^2)^{\frac{1}{2}}$ and depends on applied frequency as long as $c\omega$ is less than ik, i.e. as long the frequency is less than $ik/2\pi c$. Above this frequency, the order of 10^5 c/s, the charging current amplitude will equal to eik.

That the charging current is proportional to e and t was verified experimentally. Fig. 4 is the output current/an logue potential characteristic for a type 09J tube (by Coss Instruments Ltd.) and Fig. 5 shows the variation of out with beam current for a VCR 139 tube. In both cases spot was stationary. It can be seen that the output al was substantially proportional to *e* and to *i* for values greater than 20 V and for beam currents less than about μA.



ig. 4. Output current/analogue potential characteristic

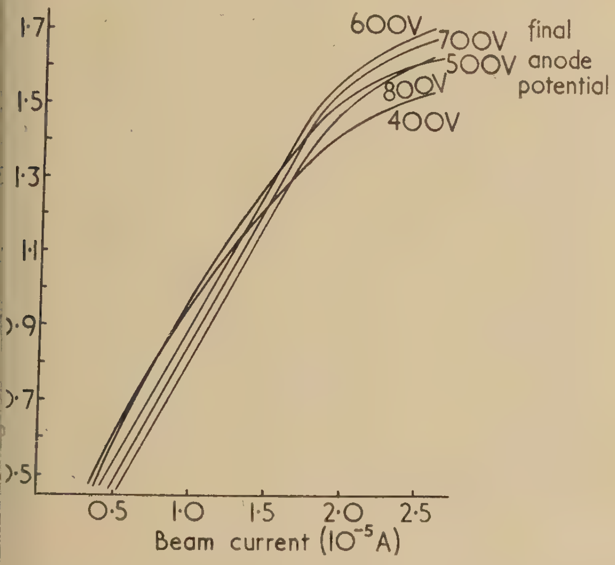


Fig. 5. Variation of output with beam current

THE PICK-UP TUBE

Cossor type O9J cathode-ray tube was used for the surement of the analogue potentials because:

a) it required a final anode potential in the region of 1000 V, a value associated with high secondary emission from the phosphor,

b) it had no internal graphite coating. The presence of a large conductor inside other cathode-ray tubes either shunted much of the secondary emission current to earth or, if it was used as the pick-up electrode, the relatively large capacitance between it and the analogue tank proved objectionable,

(*c*) the neck of the tube was not too wide to permit of electromagnetic deflexion. It had been found that electrostatic deflexion resulted in a great deal of interference with the signal, due to the deflector plates intercepting an appreciable fraction of the electron beam, this fraction varying from point to point on the screen.

The tube had the disadvantage that its screen was far from flat.

The physical arrangement of the analogue tank and pick-up tube is shown in Fig. 6. Only a small area of the screen was actually used as the bottom of the analogue tank because of its curvature. The final anode was used as the secondary emission current collector. A large conducting body placed anywhere but directly beneath the tank may result in a sensible difference between the potential field just above and just below the screen. No conductor was therefore allowed near the tank except for the graphite screening round the tube, which was earthed.

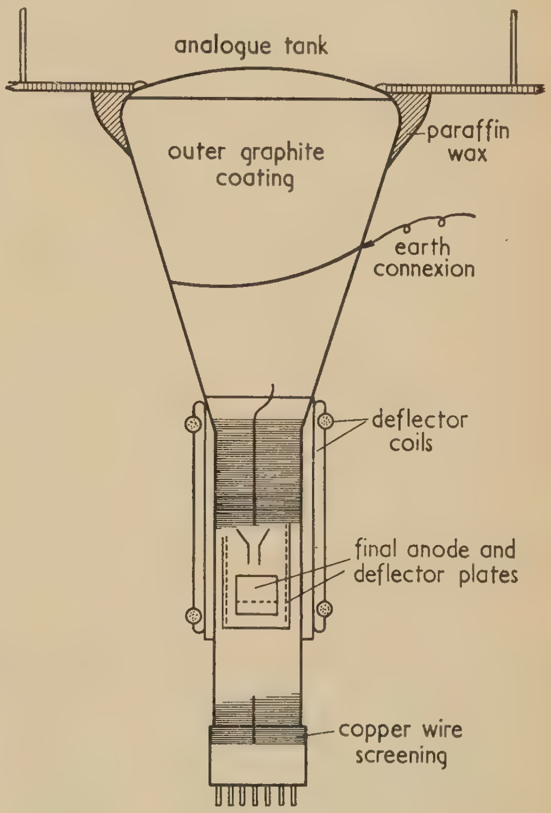


Fig. 6. The pick-up tube and tank

The analogue tank was supplied with a potential of about 100 V at a frequency of $75\cdot10^4$ c/s and the signal potential, in the form of a modulated carrier wave, appeared across an inductance of 10^{-4} H connected between the final anode of the tube, to which the deflector plates were strapped and earthed, Fig. 7. Low frequency interference from the time bases and from periodic screen charging phenomena was easily attenuated.

After amplification, the carrier was detected and the signal amplified to a peak potential of 100 V. Fig. 8 is an oscillogram of the amplified signal obtained from the field between two parallel straight plates. The line time base frequency was, in this case, 3000 c/s. The dark breaks in the traces were caused by the triggers that darkened the beam at seven equipotential values. The pick-up tube beam was tracing out a complete raster, part of which fell outside the area covered by the tank, with the result that a proportion of the lines did not coincide with the approximately straight line in the centre of the picture.

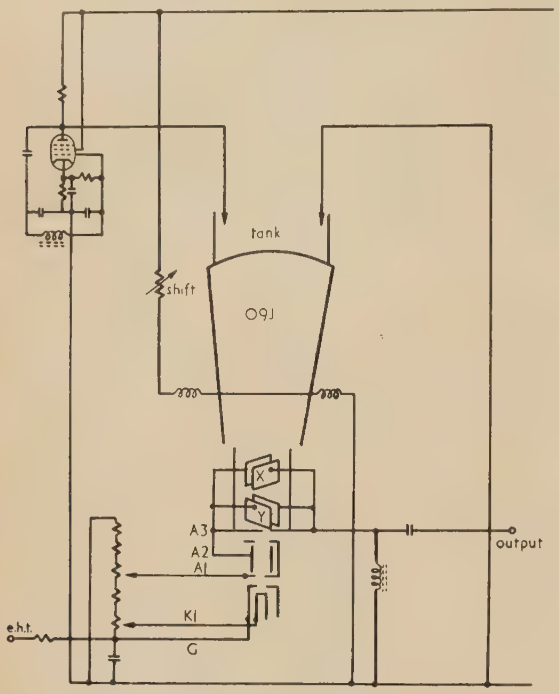


Fig. 7. Pick-up tube connexions

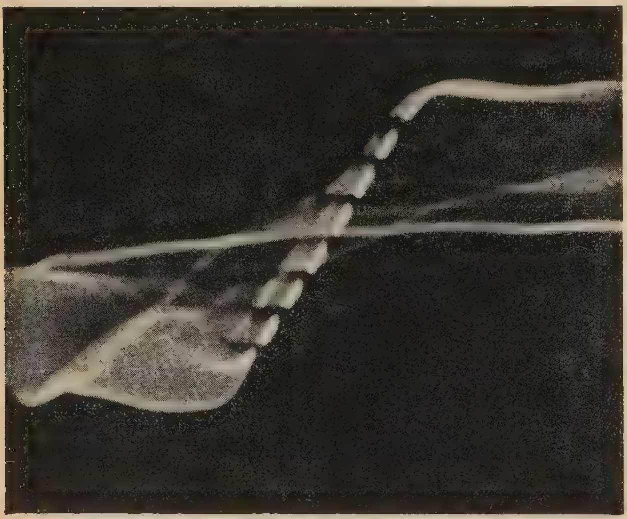


Fig. 8. Oscillogram of pick-up tube signal output

Fig. 9 shows the field map obtained under the same conditions. The line time base frequency was again 3000 c/s, while the frame time base was held at a frequency of 25 c/s. The equipotential lines were especially thickened to make the map easier to photograph and the boundaries have been inked in afterwards. A certain amount of mains interference at 100 c/s can be seen, together with the twisting of some of the equipotential lines due to trapezium distortion in th display oscilloscope. The fringing at the top and the botto of the field map is the result of the small size of the analog tank relative to the pick-up tube raster.

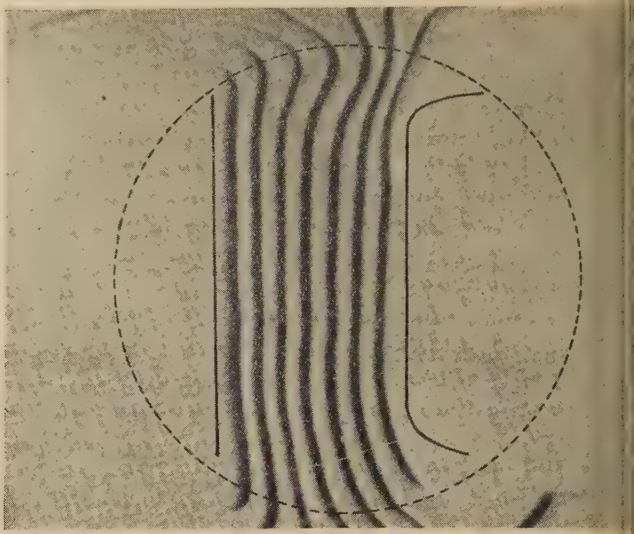


Fig. 9. A map of the field between parallel plane electrodes

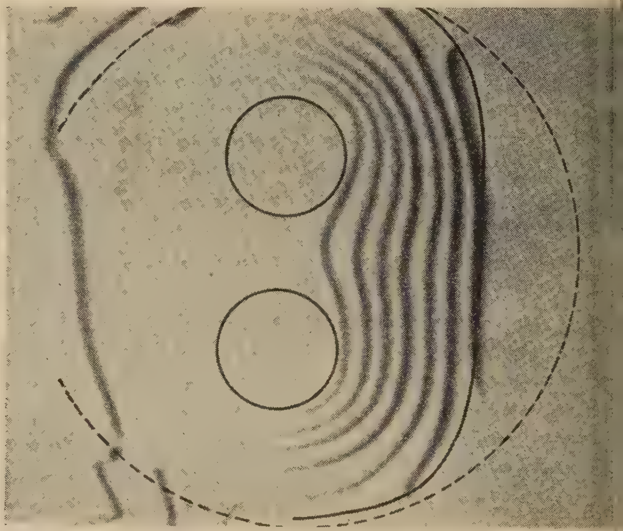


Fig. 10. A map of the field between two "h.t." windings and the tank of a "power transformer"

Fig. 10 is the map of the field between two "h.t. windings and the "tank" of "a power transformer."

THE EQUIPOTENTIAL TRIGGERS

A series of Schmidt triggers were employed to produc microsecond pulses at seven equidistant potential values the amplified signal, see Fig. 11. The triggering potential each trigger could be adjusted within wide limits by varyin its cathode resistor without deterioration of the pulse shape After amplification, the pulses were fed to the displa oscilloscope to produce equipotential lines.

The use of Schmidt triggers was extravagant. The fac the resetting pulse occurred at a different potential to at which the triggering pulse occurred meant that the ier had to be suppressed. Two triggers thus had to be for each equipotential line if it was to be displayed ng both positive and negative signal potential gradients. igs. 7, 8 and 9 only one trigger was employed for each potential line, and lines were displayed only during tive signal potential gradients.

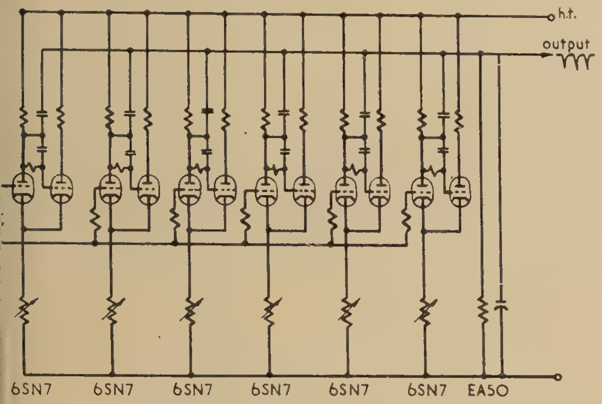


Fig. 11. The triggers

ANALYSIS OF THE ERRORS

he main errors resulted from:

) trapezium distortion of the rasters,
) drift of the equipotential triggers,
) loss of pick-up current as the detector tube spot approached the edge of the screen,
) the curvature of the bottom of the electrolytic tank,
) a.c. pick-up in the detector tube and amplifier.

The errors occurring in Fig. 9 have been analysed as far as possible, and the gross errors of various points on the equipotential lines are shown in Table 1 as the percentages of the total distance between the electrodes in the electrolytic tank. Only the centre of the field map (Fig. 12) has been included in Table 1, so as to avoid the necessity of calculating the result of end effects on the equipotential lines and as, in any case, the edges of the map are badly distorted by the loss of signal occurring as the spot approached the edge of the phosphor in the pick-up tube. This distortion caused the lines to move to the right of the map.

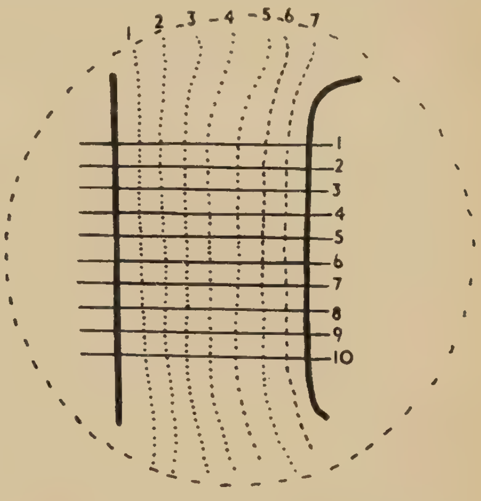


Fig. 12. The area of Fig. 9 that was analysed for errors

Trapezium distortion of the rasters accounted for a

Table 1. *Percentage departure of the equipotential lines in Fig. 9 from the theoretical values*

Equipotential lines	1	2	3	4	5	6	7	*Distance along line*
	1·4	1·7	0·7	−0·5	−3·4	−4·2	−5·1	1
	1·4	1·3	1·5	−0·5	−2·6	−3·4	−5·1	2
	1·0	0·6	0·3	−0·5	−2·6	−3·0	−4·4	3
	1·0	1·3	0·7	0·6	−1·8	−1·9	−2·7	4
	1·4	0·2	0·7	0·6	−1·0	−1·9	−2·7	5
	1·4	0·2	0·7	0·6	−0·2	−1·1	−2·0	6
	1·0	−0·2	0·7	0·6	−1·0	−1·1	−2·0	7
	0·6	−0·2	0·7	−0·1	−1·0	−1·1	−2·0	8
	0·6	−0·2	1·1	0·6	−0·1	−0·7	−0·8	9
	0·6	0·2	1·1	1·4	−0·2	−0·7	−0·8	10

Table 2. *Percentage departure of the equipotential lines from the theoretical values, after allowance has been made for trapezium distortion of the rasters*

Equipotential lines	1	2	3	4	5	6	7	*Distance along line*
	0·4	1·7	1·7	1·5	−0·4	−0·2	−0·1	1
	0·5	1·3	2·4	1·2	0·1	0·1	−0·7	2
	0·2	0·6	1·0	1·0	−0·2	0·1	−0·5	3
	0·4	1·3	1·4	2·0	0·2	0·8	0·6	4
	0·9	0·2	1·4	1·7	0·6	0·4	0·0	5
	1·0	0·2	1·2	1·5	1·1	0·7	0·2	6
	0·7	−0·2	1·0	1·3	−0·0	0·2	−0·4	7
	0·4	−0·2	0·9	0·3	−0·4	−0·2	−1·0	8
	0·5	−0·2	1·2	1·7	−0·2	−0·3	−0·3	9
	0·6	0·2	1·1	1·4	−0·2	−0·7	−0·8	10
Drift	0·7	0·8	1·7	1·1	0·4	0·1	−0·2	
Maximum basic error	±0·4	±0·95	±0·75	±0·85	±0·75	±0·75	±0·8	

widening of the upper part of the map by 5%. (Trapezium distortion in the direction of the equipotential lines is not, in this case, significant.) Table 2 shows the errors present when trapezium distortion has been accounted for. It will be noticed that some of the equipotential lines are displaced as a whole either to the left or the right by as much as 1·7%. Temperature changes of the trigger cathode resistors caused constant drifting of the equipotential lines, and the use of wire wound resistors, or some form of pulse forming tube⁽⁷⁾ would have reduced these errors considerably.

The departure of the equipotential lines from the theoretical straight line, once trapezium errors and drift of the lines are neglected, is shown in Table 2 and reaches a maximum value of just below ±1%.

In this particular arrangement of electrolytic tank electrodes the depth of the electrolyte along any line at right angles to the equipotentials did not change more than 10%. Any errors resulting from the curvature of the bottom of the tank would therefore be small compared with the trigger drifts. No trouble was experienced from the presence of "phonies" (i.e. small voids in the phosphor layer), in the phosphor. In any case, errors due to this cause would be expected to result in a series of spots appearing over the field map and unless present in large numbers would not be serious.

The purpose of the field mapper was to demonstrate the principle of an electronic method rather than to make an accurate instrument, which would, in any case, need to have a much larger electrolytic tank. Typical accuracies expected in power engineering are to between 1% of the applied voltage⁽⁸⁾ and to 0·1% of the voltage gradient⁽⁹⁾ and it may well prove possible to attain an accuracy between these limits by careful design of the device.

CONCLUSIONS

The mechanism of phosphor potential stabilization has been thoroughly discussed in the literature and the detection of potentials by this means has been used as the basis of television camera tubes for some years. The detection of potentials impressed on the end of a cathode-ray tube by an electrolytic tank differs from that in a camera in two main respects:

(1) the potentials on a camera tube mosaic are built up between sweeps of the beam by charges due to photo-emission (or secondary emission in the case of image-type tubes). The stabilizing charges are thus neutralized, or partially neutralized, between each sweep, and when the spot returns a second time a further stabilizing charge is deposited. These stabilizing charges are proportional to the light intensity at any point on the mosaic and constitute the signal from the tube. In the field mapper, on the other hand, no charges are accumulated on the phosphor between sweeps and when the beam returns to a previously swept part of the phosphor substantially no further stabilizing charge is deposited and no signal is obtained. This disadvantage was overcome by using alternating potentials in the electrolytic analogue;

(2) large potentials can be impressed on the screen of the tube by the analogue, and the charges associated with these potentials, and the capacitance between the spot and the analogue tank are much larger than those that can be built up on the mosaic of a camera tube by photo-emission. A much larger signal is thus obtained in spite of the relatively low secondary emission ratio of the phosphor.

The main purpose of the mapper was to demonstrate the method used and no effort was made to investigate errors resulting from the redistribution of stabilizing charges over the screen, under certain conditions, from capacitance effects in the tank and from the curvature of the bottom of the analogue.⁽⁷⁾ An analysis of the errors occurring in Fig. suggested that the errors from these sources did not result in the displacement of an equipotential line by more than ±1%.

ACKNOWLEDGEMENTS

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An improved automatic fraction collector

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A fraction collector for chromatography is described which incorporates a new type of liquid dispenser, photo-electrically operated, and capable of delivering predetermined, fixed volumes despite variations in rate of outflow from columns, and changes in density of the liquid.

majority of fraction collectors(1, 2, 3, 4) are designed to sure a constant weight of liquid but where the density he liquid is changing continuously it is preferable to sure constant volumes. This has previously been mpted with fraction collectors(5, 6, 7) and with liquid ensers,(8) but most were considered unsatisfactory for purpose. The present work describes an instrument ch can deliver accurate volumes despite variations in flow and density of liquids.

AUTOMATIC LIQUID DISPENSER

he dispenser (Fig. 1) consists of a reservoir chamber *D* nected to a measuring chamber *E*, with a side arm *Q* ed to it as near to the outlet as possible. The measuring

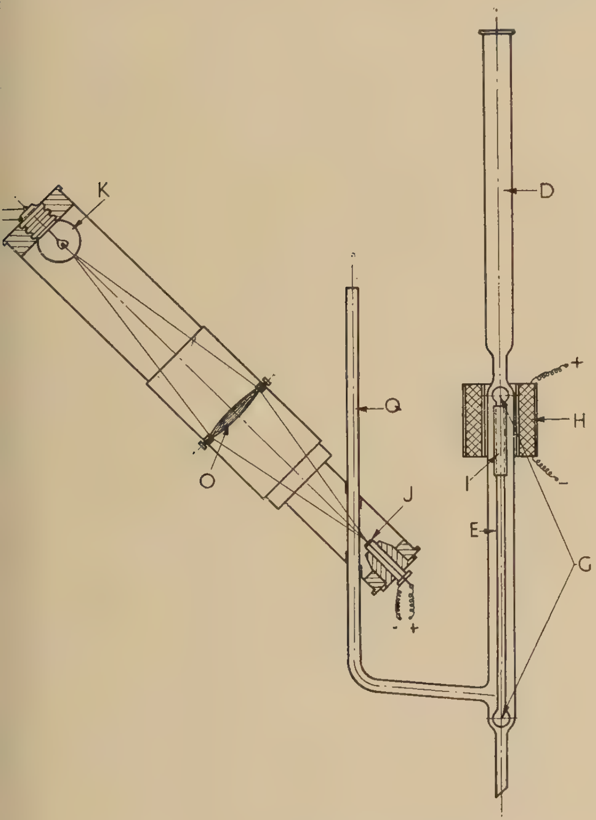

Fig. 1. Automatic liquid dispenser

mber *E* contains a double-valve plunger *G* with spherical ts bearing on spherical surfaces. These are carefully ed to retain organic solvents such as chloroform, acetone enzene. The throw of the plunger should be no more 0·5 cm. A soft-iron slug *I* is sealed into the plunger nediately below the top spherical joint, and the outer tube at this point is surrounded by a solenoid *H* consisting of a replacement coil for a Goyen magnetic valve type SW. This coil has inside and outside diameters of ¾ and 2¼ in. respectively, a winding length of 2 in., and is wound with 34 s.w.g. gauge wire providing a resistance of 450 Ω and operates with a direct current of 180 mA.

The optical system consists of a single transverse filament lamp *K*, a 3¾ in. focal length convex lens *O*, and a germanium phototransistor (Standard Telephones and Cables type P50A) *J* of small light-sensitive area (0·06 × 0·02 in.), which does not require an optical slit to achieve accurate level measurement. These are mounted, but separately adjustable, in a brass tube inclined at 45° to the side arm *Q* of the dispenser, which passes through a hole in the tube immediately in front of the photocell. A desirable feature of the photocell used is the large change of "on" to "off" current. When 26 V is applied across the phototransistor and relay in series, a current of 1·25 mA flows when no liquid is in the side arm, but this falls to 50 μA when liquid interrupts the light beam. As a pull-in current for the relay is 800 μA and the fall-out current is 400 μA, a large safety design-factor is available.

The optical system is mounted on a stage which can be racked vertically, thus enabling variation in the volume of liquid dispensed to be obtained.

TURNTABLE CONSTRUCTION

The turntable consists of a 25 in. bicycle wheel with a peripheral wooden collar containing 80 evenly spaced ¾ in. holes, and the same number of clips around the outer circumference. It is actuated by an electric motor (Fig. 2) having a speed of 1425 r.p.m. connected through a 60/1 reduction gear, the shaft of which carries a rubber cone bearing on the underside of the wheel. The underside of the wheel is slotted to take the roller of a microswitch and there are as many slots as collecting tubes. The motor drive and the microswitch are mounted on a hinged spring-loaded platform beneath the

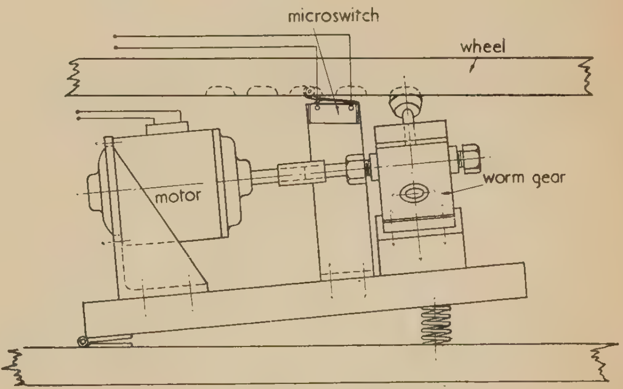

Fig. 2. Drive, showing microswitch

wheel, which takes up the variations with load in the level of the wheel.

CONTROL SYSTEM

The circuit for the automatic fraction collector is shown in Fig. 3. With switch S_1 closed and switch S_2 set on "rotate" the wheel carrying the collector tubes is rotated by the motor. Tubes can be inserted as the wheel turns, the speed of progression past a given point being approximately one tube holder each five seconds. When ready for operation S_2 is returned to the "wait" position and the motor will no longer revolve, because the microswitch S_3 situated under the wheel will be in the "open" position, due to the alinement of the slots on the underside of the wheel. The roller of the microswitch bears against the underside of the wheel during rotation, but rises into a lot so placed that it corresponds with the arrival of an empty tube beneath the dispenser outlet. The rise of the microswitch roller opens S_3 and stops further rotation of the motor. In the "wait" position power is fed to the lamp, the phototransistor is illuminated and relay A is pulled in opening up the "operate" coil of relay B. Because relay B is "normal" in the "reset" position the time-delay mercury contact b_2 is already closed and relay C is therefore shorted out. Contact b_1 is open, preventing energizing current passing through the solenoid.

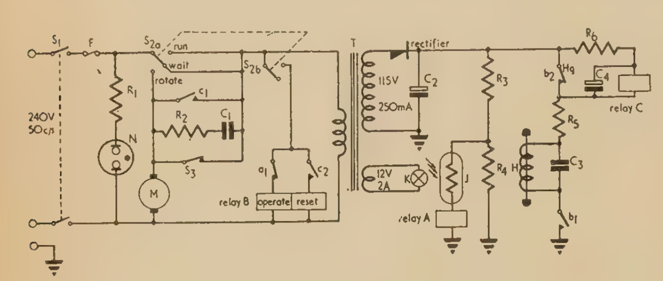

Fig. 3. Circuit diagram of confrol system

R_1 = 250 kΩ
R_2 = 100 Ω
R_3 = 14 kΩ w.w.
R_4 = 4 kΩ w.w.
R_5 = 50 Ω w.w.
R_6 = 47 kΩ

C_1 = 0·05 μF, 600 VW
C_2 = 8 μF, 350 VW
C_3 = 24 μF, 350 VW
C_4 = 24 μF, 350 VW

Rectifier = 120 V, 250 mA half-wave

K = projector lamp, Class F, 12 V, 24 W (by Edison Swan Electric Co. Ltd.)
S_1 = toggle D.P.S.T. 2 A
$S_{2a, 2b}$ = wafer 2-pole, 3-position
S_3 = microswitch—Burgess BRL2R

F = fuse (2 A)
M = motor, type 1304, 240 V 50 c/s, 9 W, 1425 r.p.m.
T = transformer 240 V/115 V, 250 mA, 12 V, 2 A
J = germanium phototransistor S.T.C. type P50A
H = solenoid coil, Goyen magnetic valve type SW
Relay A = S.T.C. type 5101 AHX-20 000 Ω coil 1 × N/O contact
Relay B = Londex type LQA/double a.c. latching relay 1 × N/O 20 second-delay mercury contact 1 × N/O H.D. contact
Relay C = S.T.C. type 4660 10 000 Ω coil 2 × N/O contacts
N = neon type NE51

OPERATION

Switch S_2 is set to the "run" position. Liquid entering th dispenser passes through the reservoir chamber D into th measuring chamber E, but the double-valve plunger G block the outlet to the collector tube, since the solenoid H is no energized. When the liquid level in the side arm Q intercept the light beam, the latter is refracted down the side arm an causes relay A to fall out. Contact a_1 closes, energizing th "operate" coil of relay B. This tilts the mercury dela contact b_2 and closes contact b_1, energizing the solenoi The double-valve plunger rises, preventing the liquid fro entering the measuring chamber and at the same time allowing the liquid in the latter to run into the collector tube The plunger is held in this position for 20 s, the time take for the mercury delay contact b_2 to open, after which th plunger drops and a fresh supply of liquid enters th measuring chamber from the reservoir chamber. As conta b_2 opens the short is removed from relay C, which operate closing contacts c_1 and c_2. The closing of c_2 resets relay

Condenser C_4, which charges when contact b_2 opens, now discharged through relay C, holding the relay in fo about a second. The motor is energized through contact for this period and keeps rotating because the microswitc S_3 is now closed. This rotation continues until a ne collecting tube is in position under the dispenser, when opens again, stopping the motor. The next cycle th begins.

The dispenser is capable of delivering a predetermi volume with an accuracy of about 0·5%. Even at relatively high flow rate of 24 ml/min the reproducibility about 1%. The instrument has operated satisfactorily about six months.

ACKNOWLEDGEMENTS

The authors are indebted to Mr. J. Johannsen for most the mechanical fabrication, Messrs. D. Swingler and M. Willing for assistance with the electronics, and Mr. Simpson for drafting.

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An ultra-microtome

By A. L. Sims and T. S. Leeson, M.A., University College, Cardiff

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The instrument is so designed that it can be made in a laboratory workshop where a lathe and a milling or shaping machine are available. The body of the machine is made of a metal with very small coefficient of expansion and carries both the knife and the specimen-holder. The coefficient of expansion of the latter is six and a half times that of the body of the machine and the specimen is moved over the knife by heating this holder. A clear visual field is provided for the operator to cut sections under a binocular microscope. Provision is made for easy handling of the cut sections. To avoid vibration while cutting, the specimen holder is rotated magnetically. Cutting is fully automatic and sections of 1/40 μ (250 Å) can readily be obtained.

:ient and durable ultra-microtomes are costly, and a essful attempt has been made to construct a reliable and ise instrument which can be made in a laboratory work-), where a lathe and a milling or shaping machine are lable.

PRINCIPLE AND DESIGN

he body of the instrument, which carries both the knife the specimen-holder, is made of a single block of metal y (Nilo 40, made by Henry Wiggin and Co. Ltd.) of a low thermal expansion which changes only very slightly linearly over the temperature range 0–150° C. The knife eld stationary on the body while the specimen-holder, a s rod, is mounted in ball bearings in such a way that n it is heated its expansion advances the specimen over knife. The rod is of 65/35 brass which has a coefficient xpansion which varies linearly over the effective tempera- range and is about six and a half times that of the Nilo 40. ıched to the brass specimen-holder are two bar magnets, the rotation of the holder is effected by the rotation of ther pair of magnets carried on the shaft of an electric or. The specimen-holder is made to rotate at a constant so that, provided the knife is adequately sharp, the only able in determining thickness of sections is the rate of ing. The specimen-holder is heated electrically but vision is made for alternative heating by Bunsen burner y solid fuel. The Bunsen burner also provides a channel which air can be blown on to the electric heater and so en the cooling of the specimen-holder. The site of cutting nobstructed and the process is fully automatic so that the rator, with both hands free, may observe it through a ocular microscope. The transfer of the sections to an tron-microscope grid from the water-acetone bath into ch they pass from the knife is facilitated by the presence small platform abutting on the bath. The size of the rument is 20 × 14 × 9 cm and it weighs 12½ lb.

CONSTRUCTION

he various features of the instrument are shown in Fig. 1. *he knife* (21) is made by scratching with a diamond at an le of 45° across a strip of frosted glass plate, 40 mm wide 6 mm thick, to make a rhomboid with sides of approxi- ely 25 and 55 mm. Alternatively, a specially sharpened r blade may be used but, even when supported within m of its edge, such a blade may be distorted on the impact methacrylate block. A glass knife has been found to sections with fewer scratch marks and is in every way er. Accurate adjustment of the knife is not necessary. It amped with its cutting edge near the end of the specimen- ler and the fine adjustment is made by sliding the specimen block along the V-groove in its holder until it touches the knife where, viewed by the binocular microscope, it is clamped.

The specimen-holder (6). Holes with lock screws and spring collets were both found to be unsatisfactory means of holding the specimen block, and the method adopted is to clamp the block into a V-groove cut eccentrically in the rotating holder.

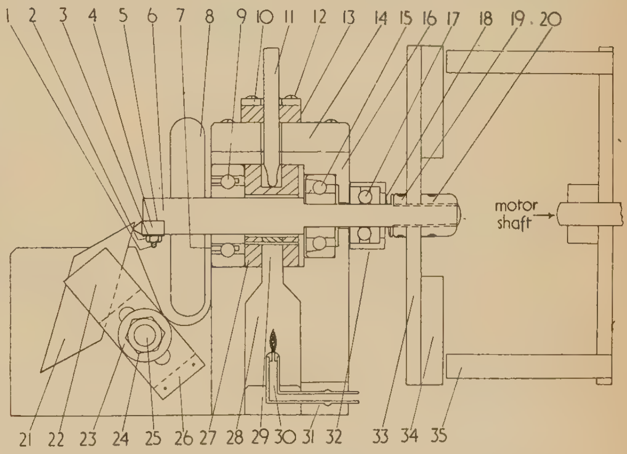

Fig. 1. Diagrammatic half-section view of ultra-microtome

(1) 6 BA stainless steel screwed stud; (2) 6 BA brass nut; (3) brass pressure plate; (4) methacrylate specimen block; (5) V-groove; (6) specimen-holder; (7) brass cover; (8) brass wheel; (9) ball journal race; (10) brass washer; (11) thermometer; (12) 4 BA screws; (13) rubber washer; (14) Mycalex plate; (15) ball race, angular contact; (16) body, Nilo 40; (17) ball thrust race; (18) spring washer; (19,20) brass nuts; (21) glass knife; (22) clamp, Nilo 40; (23) washer, Nilo 40; (24) nut, Nilo 40; (25) screwed stud, Nilo 40; (26) polythene distance piece; (27) electric heater; (28) hole, 25 mm diameter; (29) hole, 8 mm diameter; (30) brass Bunsen burner; (31) slot; (32) brass cover; (33) Duralumin plate, driven; (34) rectangular magnets; (35) cylindrical magnets.

The wheel (8) is sufficiently heavy to keep the specimen holder pressed downward in its bearing. Any upthrust in cutting, which could reveal any lack of precision in the ball races, is thereby avoided. The momentum of the wheel smooths any irregularity in movement during cutting.

The heater (27) is a miniature soldering iron element of small cost, rectangular in section and measuring 32 × 10 × 2·25 mm, and rated 25 W at 220–240 V. The current to the heater is controlled by a rotary rheostat and is registered by a milliammeter which can conveniently be calibrated in terms of expansion (section thickness).

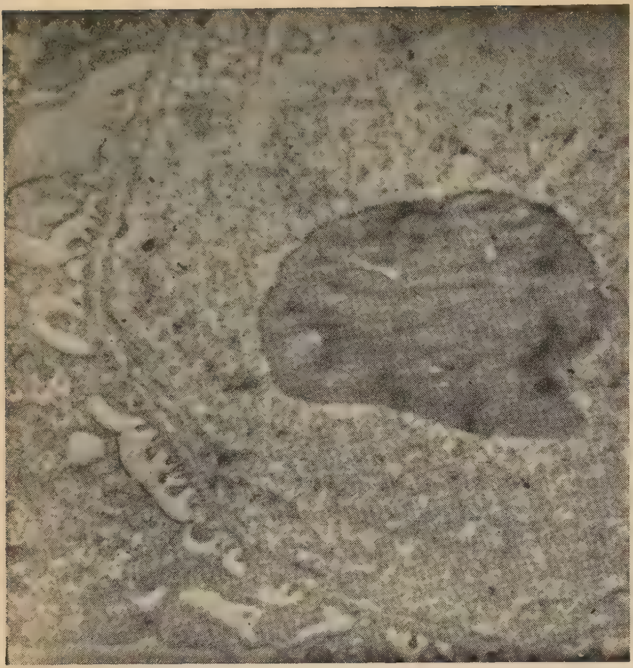

Fig. 2. Photomicrogram of a section of the foetal kidney from a seventeen-day rabbit embyro. Approximate magnification × 16 000

PERFORMANCE

For a temperature rise of 80° C (20–100° C) the specimen is moved 0·254 mm giving ample scope for cutting a number of sections. For each reading on the milliammeter, in series with the heater, a particular and constant thickness of section can be obtained. From specimens fixed in osmium tetroxide and infiltrated with and embedded in methacrylate, sections of 1/40 μ (250 Å) can readily be cut. Shielding of the instrument from draughts is necessary. When cutting without the Perspex cover which normally shields the instrument, the movement of a person near it may break the continuity of serial sectioning by altering the rate of heating. With the cover in place this disturbance does not occur. Sections may be cut by rotating the wheel by hand but more precise results are obtained with the magnetic rotator.

The photomicrogram (Fig. 2) is of a 200 Å thick section of the foetal kidney from a seventeen-day rabbit embryo. The large dark mass on the right is a red blood corpuscle about 5 μ in diameter.

Detailed constructional drawings are available for copying and can be sent to anyone wishing to make the Sims–Leeson ultra-microtome.

ACKNOWLEDGEMENTS

Our thanks are due to Mr. D. H. Brown and to Mr. D. K. Warman for making the instrument and accessories respectively.

A steady state method for the rapid measurement of the thermal conductivity of rocks

By A. Beck, B.Sc., A.Inst.P.,* Australian National University, Canberra, Australia

[*Paper received* 15 *October*, 1956]

The principle of constant temperature difference is used in a divided bar type of apparatus with which a measurement of the thermal resistance of a specimen can be completed within twenty minutes. A thick guard ring is used. The diameter of the specimens is made the same as the external diameter of the guard ring, and irregularities in disks, which would cause appreciable errors in a more conventional apparatus, can be tolerated and an accuracy of ±1% for a single measurement still be obtained.

It is well known that when the divided bar method is used for the measurement of the thermal conductivity of rocks, the time for a single specimen to reach equilibrium is usually in excess of one hour. However, if the time required is estimated theoretically it can be seen (Appendix) that almost all the time lag is due to apparatus design and that a suitably constructed divided bar apparatus should reach the steady state within ten minutes. This comparatively short time interval is desirable, not only because of the time saved, but also because little accurate work has been done on the variation of the thermal conductivity of porous rocks with changes in water content; it is not possible to do this by methods involving long time lags since they give inaccurate results due to evaporation and migration of the water.

In the divided bar method a disk of rock is introduced between two cylindrical metal bars, usually brass, and heat is supplied to the remote end of one bar while the remote end of the other is cooled with thermostatically controlled water. By making temperature measurements in the bars after the steady state has been reached, the thermal conductivity of the specimen is determined in terms of the conductivity of the bars. The effect of the thermal contact resistance between the bars and the specimen is eliminated by making measurements with three or more disks of different thicknesses. In general, the bars are arranged vertically with an electrical heater, at the top end of the upper bar, situated under a platform on which weights are placed to make the contact resistance as uniform as possible. Theoretically, in the conventional type of electrically heated divided bar, heat is supplied at a constant rate so that when the total thermal resistance is altered by changing a specimen then, because the bottom end is controlled thermostatically, the temperature has to change at various points along the system and in particular at the heater end of the bar. It is here that the main time lag occurs for in many apparatuses a comparatively small heater supplying approximately 1 cal cm^{-2} s^{-1} has to heat a large mass of metal weighing between 20 and 30 lb. Furthermore, the thermal insulation around the metal bars also causes a time delay since this too has to reach equilibrium.

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t is interesting to note also that when using a set of three more disks of rock it is generally assumed that during the asurements the contact resistance and the rock specimens at a given mean temperature; to a first approximation s is true provided that the thermal resistances of all the cimens to be measured are nearly equal. However, it can dily be seen that if changing a specimen causes the total rmal resistance to increase then, if it is assumed that the per end is supplied with heat at a constant rate and since bottom end is controlled thermostatically, the mean nperature of the upper bar rises while that of the lower r remains constant, so that the mean temperature of both specimen and the contact resistance increases. This ect is partly reduced in practice because heat is not supplied a constant rate to the divided bar section of the apparatus: one specimen is replaced by another of higher thermal istance then the rate of supply of heat will fall since the ter supplies heat to both the weight platform and the ided bars. The equivalent electrical circuit is a high istance connected in parallel to a low resistance and wer applied such that the sum of the currents in the two istances is constant. With materials of intermediate con-ctivity, such as rocks, this effect is not appreciable, but it plains the limitations of this type of divided bar apparatus bad conductors.

Various methods to overcome the above objections were nsidered including transient methods. These may be made ite rapid but they can never be as accurate or as reliable steady state methods.

THE APPARATUS

In the arrangement finally adopted, the electrical heater s discarded and the top end controlled thermostatically at emperature 17° C above the temperature of the bottom d. The electrical analogy is that the apparatus is now a nstant voltage system.

Because the diurnal fluctuations in temperature are so ge in Canberra some form of guard ring was considered essary. Since to aim for extreme accuracy would have olved separate cooling systems for the inner bar and ard ring and other practical difficulties, the apparatus was nplified by using a shower form of cooling which distri-ted water on to the end surfaces of the bars and allowed th the inner bar and guard ring to be incorporated into e shower. The position of the specimen and the essential tures of one bar are shown in Fig. 1(*a*); the other bar is ntical.

The inner bars were made $\frac{7}{8}$ in. in diameter and the guard gs 1 in. internal diameter and 1$\frac{3}{8}$ in. outside diameter; all tions were turned from the same rod of brass. A ring of ass of 1 in. outside diameter, $\frac{7}{8}$ in. inside diameter and in. thick was hard soldered into one end of each bar and ard ring, and the rest of the interspace was filled with a se-fitting cylinder of polythene. This ensured that the ner bars and guard rings were rigid assemblies and remained ncentric. The ends of the composite bars were turned on athe and the specimen faces lapped flat with a fine powder; owers were fitted to the other ends of the bars.

Into each bar three radial holes were drilled $\frac{1}{16}$ in. in ameter and penetrating $\frac{1}{4}$ in. into the inner bar. The holes re spaced along the bar at 1 in. intervals with the first le $\frac{1}{4}$ in. away from the specimen end and the last approxi-tely 1 in. from the shower. In the plan view, Fig. 1(*b*), angle between each hole is 120°, but they are shown in e in Fig. 1(*a*). Into these holes, numbered 1 to 6 from the top, were placed calibrated copper–constantan thermocouples made out of 40 s.w.g. wire and soldered into a hollow brass sleeve which was $\frac{5}{8}$ in. long, 0·04 in. internal diameter and fractionally less than $\frac{1}{16}$ in. outside diameter. Great care was taken to ensure that the two wires were touching only at the inner end and were situated centrally. One turn of the wires was taken round the bar to eliminate conduction errors, and one or two thicknesses of glass tape were wound on to give some protection from draughts and to prevent the fine thermocouple wires being damaged. The associated thermocouple equipment was a type K. 2 potentiometer (by Leeds and Northrup Company).

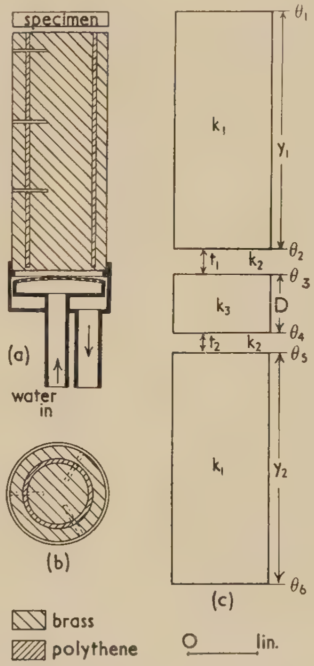


Fig. 1. "Constant temperature difference" divided bar apparatus

An ebonite platform to carry weights was built around the upper shower. The lower bar was rigidly fixed to an ebonite stand and the upper one left free to move both vertically and horizontally. The showers were thermally insulated by polythene, $\frac{5}{16}$ in. thick, over which were mounted draught screens which were pulled down when the apparatus was running.

THEORY

If there are no heat losses from the sides and if the equilibrium heat flow is H cal cm^{-2} s^{-1}, then for any material

$$H = k(d\theta/dx) \qquad (1)$$

where k is the thermal conductivity of, and $d\theta/dx$ the temperature gradient along the material.

From equation (1) and Fig. 1(*c*) five separate equations for H may be written. They are

$$\begin{aligned} H &= (k_1/y_1)(\theta_1 - \theta_2) = (k_1/y_2)(\theta_5 - \theta_6) = (k_2/t_1)(\theta_2 - \theta_3) \\ &= (k_2/t_2)(\theta_4 - \theta_5) = (k_3/D)(\theta_3 - \theta_4) \end{aligned} \qquad (2)$$

Also

$$\begin{aligned} \theta_1 - \theta_6 &= (\theta_1 - \theta_2) + (\theta_2 - \theta_3) + (\theta_3 - \theta_4) + \\ &\quad + (\theta_4 - \theta_5) + (\theta_5 - \theta_6) \end{aligned} \qquad (3)$$

therefore, from equations (2)

$$C_1/(d\theta/dx) = B_1 + (D/k_3) \qquad (4)$$

where $C_1 = \dfrac{\theta_1 - \theta_6}{k_1}$ $\quad B_1 = \dfrac{y_1 + y_2}{k_1} + \dfrac{t_1 + t_2}{k_2}$

θ_1, θ_6, y_1, y_2, k_1, k_2, t_1, t_2 are constant and $d\theta/dx$ is the temperature gradient in the brass.

A plot of the reciprocal of $d\theta/dx$ against D gives a straight line of slope $1/k_3$. By measuring the temperature at one point of known distance from the shower end of one of the bars, it is theoretically possible to find $d\theta/dx$, since the temperature of each shower is known. However, in practice the guard ring does not completely eliminate heat losses from the sides so that values of $d\theta/dx$ would be inaccurate if they were derived over too long a length of the bar or too far from the specimen end. It is also found desirable to alter θ_1 and θ_6 occasionally and the more convenient and more usual equation can be derived from equations (2); these give

$$\Theta/(d\theta/dx) = B_2 + (k_1/k_3)D \qquad (5)$$

where Θ is the temperature difference between the two faces of the bars in contact with the specimen and $B_2 = k_1(t_1 + t_2)/k_2$.

Since the specimen occupies the whole of the guard ring and measuring area and since these two areas are separated by a gap of $\frac{1}{16}$ in., a standard diameter correction(1) has to be applied to each disk; this correction varies from 4% for a disk 2 mm thick to 10% for a disk 8 mm thick.

EXPERIMENTAL PROCEDURE

In an experiment a specimen was placed between the bars which were then lined up with one of a number of sets of brass formers. Each set of formers consisted of a brass tube, $1\frac{3}{8}$ in. internal diameter, cut in half and with a length appropriate to the disk being used; for example, a former 8 mm long was used with a disk 4 mm thick. With the specimen roughly in place the two halves of the former were pressed against the two brass bars and pushed firmly together to bring the bars and specimen exactly into line. Weights were then added to the platform to produce a pressure of approximately 20 lb/in.^{2} Starting from a time ten minutes after the specimen was placed in position, each thermocouple was read every five minutes until three consecutive sets of readings agreed with one another to within 1 μV. In general it was found that the first three readings were sufficient and were within 0·5 μV so that a measurement on one disk was completed in twenty minutes. The temperature gradient in each bar was determined from the two extreme thermocouples and a value for the thermal resistance of a specimen was found from the mean of the two temperature gradients which usually differed by less than 1%.

PERFORMANCE

Time to reach equilibrium. To indicate the time to reach the steady state under various conditions, the rise in temperature of thermocouple No. 3 is plotted against time in Fig. 2. Curve (1) was obtained by starting to pass water through the showers at time $\tau = 0$ with no specimen between the bars. The corresponding case with a disk of fused silica, 6 mm thick, between the bars is shown in curve (2).

The apparatus was allowed to reach equilibrium with no specimen between the bars and then disturbed by introducing the 6 mm disk of fused silica; the time taken to reach a new equilibrium is shown in curve (3). The corresponding case for a disk of crystalline quartz, 2 mm thick, is shown in curve (4). It will be noted that in every case it takes less than twenty minutes for the apparatus to reach the steady state from zero initial temperature and less than ten minutes after changing a specimen.

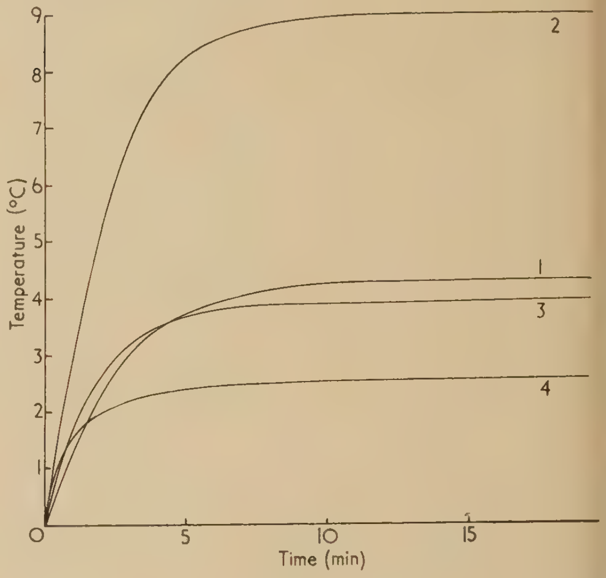


Fig. 2. Time taken by thermocouple No. 3 to reach equilibrium

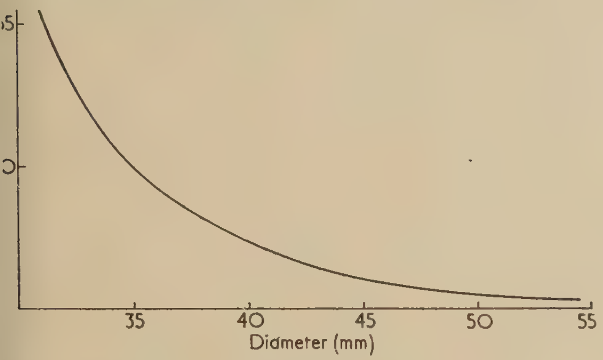
Reproducibility. Experiments with one disk of rock were carried out to test the reproducibility with air contacts and with liquid contacts at the brass specimen interfaces. For air contacts, if the specimen was removed and replaced in the same orientation the standard deviation was 0·9%. When the specimen was removed and replaced in random orientation the standard deviation was 1·1%. For liquid contacts the corresponding cases gave standard deviations of 0·7 and 1·1%. During the latter experiments the surfaces of the specimen and brass faces were periodically wiped clean and fresh liquid applied; no difference was detected in the readings. For a disk of plate glass with liquid contacts and random orientation the standard deviation was 0·6%.

Liquid contacts were used throughout all experiments since they appeared to give slightly more reliable results than air contacts. The liquid was a mixture of one part of glycerine to two parts of water and is similar to that used by Bullard.(2)

Effect of irregular disks. The thick guard ring helps to reduce the effects of irregularities in the edges of the specimens. There was no change in the thermal resistance of a disk of quartzite, 4 mm thick, which was measured both in perfect condition and after two chips, each approximately 2 mm wide by 1 mm deep, had been made into its edge.

Other disks were first measured in the perfect condition and then broken and pushed together again after they were replaced in the apparatus; there was no noticeable change in the value for the thermal resistance provided the joint came within the guard ring area. If the joint came within the area bounded by the internal radius of the guard ring, the error varied according to the length of the joint and the angle the joint plane made with the horizontal.

The standard diameter correction which has to be applied to each disk has been mentioned above. However, small errors of up to ±0·5 mm in the diameter of a disk can be rated without applying a further correction. This was wn by making a series of measurements on plate glass . thick. The first measurement was made on a rectangular e, 10 × 16 cm, symmetrically placed in the apparatus. m the centre, a series of disks 50, 35 and 31·5 mm in neter were successively cut and their thermal resistances sured. A plot of the thermal resistance of the disk plus ir films against the diameter gives the curve in Fig. 3; rectangular plate has been treated as a disk of infinite neter. It was also found that specimens could be placed ositions with an overlap of up to approximately 1 mm . no detectable change in the total thermal resistance.



ig. 3. Effect of errors in diameter on the total thermal resistance of plate glass $\frac{1}{4}$ in. thick

ffect of ambient temperature. With a mean specimen perature of 28° C experiments were performed with talline quartz and fused silica at ambient temperatures of nd 30° C. A set of three disks, 2, 4 and 6 mm thick, of talline quartz cut parallel to the optic axis from one tal, gave no detectable difference in conductivity relative he brass. However, when fused silica was used the arent conductivity with an ambient temperature of 15° C 3% lower than the conductivity determined with an ient temperature of 30° C, which showed that appreciable rs occurred when materials of low conductivity were sured with the ambient temperature much lower, or ner, than the mean temperature of the specimen.

seful range of the instrument. The brass bars were orated using the set of crystalline quartz disks described ve. At 28° C the conductivity of crystalline quartz cut llel to the optic axis is 0·0146 cal cm^{-1} °C^{-1} s^{-1}(3); ductivities quoted in this paper are based on this value. r a period of one year nine separate calibrations were le and gave a value of 0·231 ± 0·3% for the conductivity ne brass bars. To check the useful range of operation of apparatus, the thermal conductivities of crystalline quartz perpendicular to the optic axis and of fused silica were determined. In the table the values obtained in these eriments, together with the respective standard deviations, compared with the two most reliable measurements$^{(4-6)}$ viously made; the work of Kaye and Higgins, and Griffiths Kaye are treated as one.

Thermal conductivities at 28° C

Material	*Kaye, Higgins and Griffiths*	*Birch and Clark*	*Present work*
ed silica	0·00326	0·00334	0·00323 ± 0·4%
rtz cut erpendicular o optic axis	0·0256	0·0237	0·0261 ± 0·4%

The good agreement between all three sets of observations indicates that the apparatus has a useful range from 0·003 up to 0·03 cal cm^{-1} °C^{-1} s^{-1}.

CONCLUSIONS

The apparatus is capable of making rapid measurements of the thermal resistance of materials of intermediate conductivity. It is very flexible in operation; irregularities which would cause large errors with a more conventional type of apparatus have very little effect on the results obtained.

Fig. 3 indicates that the use of a second guard ring may reduce the errors caused by oversized disks sufficiently to enable reliable measurements to be made on irregular shaped plates which may be regarded as disks of infinite diameter.

A "constant temperature difference" type of divided bar apparatus could probably be built for measuring the thermal conductivity of materials as badly conducting as ebonite. If brass bars can be used to give a good value for the thermal conductivity of fused silica, the conductivity of which is two orders lower than that of brass, then with bars of a suitable material, say bismuth calibrated with fused silica, it should be possible to measure the conductivity of materials such as ebonite.

ACKNOWLEDGEMENTS

The writer would like to thank the Australian National University for a generous maintainance grant and Prof. J. C. Jaeger for much helpful advice and the material contained in the Appendix.

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APPENDIX

It can be shown that the departure of the temperature from its equilibrium value for large values of the time is proportional to $\exp(-\kappa_1\alpha^2 t)$ where α is the smallest root of

$$2\tan y\alpha \Big/ \left[\frac{k_2}{k_1}\sqrt{\left(\frac{\kappa_1}{\kappa_2}\right)}\tan^2 y\alpha - \frac{k_1}{k_2}\sqrt{\left(\frac{\kappa_2}{\kappa_1}\right)}\right] = \tan D\alpha\sqrt{\left(\frac{\kappa_1}{\kappa_2}\right)}$$

where k_1 and κ_1 are the thermal conductivity and diffusivity of brass, k_2 and κ_2 those of the disk, y is the length of a brass rod and D is the thickness of the disk.

Using the typical values $y = 7\cdot5$ cm, $D = 1$ cm, $k_1 = 0\cdot25$, $\kappa_1 = 0\cdot33$, $k_2 = 0\cdot0028$ and $\kappa_2 = 0\cdot0058$ gives $\alpha = 0\cdot199$ rad; if $D = 0\cdot5$ cm, $\alpha = 0\cdot205$ rad. These values may be compared with the value of $\alpha = 0\cdot209$ rad for the case in which the disk is not present ($D = 0$).

It appears, therefore, that the time necessary for the system to reach equilibrium is very little affected by the presence of the disk, and that after about ten minutes the departure from the equilibrium temperature should be quite negligible.

The a.c. properties of resistors and potential dividers at power and audio frequencies, and their measurement

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[*Paper received* 17 *October*, 1956]

The alternating-current properties of resistors are briefly discussed, and the time constant and equivalent series inductance and shunt capacitance are defined. The reasons for the variations with frequency are outlined. The determination of the properties is based on standard resistors with windings of simple geometry, for which the inductance and capacitance are calculable. The paper describes methods for comparing such standards with ordinary resistors, for values ranging from a small fraction of an ohm up to about a megohm; particular attention is given to potential dividers of the Kelvin–Varley type, which have great utility in these measurements. The choice of method depends upon the value of the resistor and, for low values (less than, say, 10 Ω), whether the resistor is a two- or four-terminal one.

1. INTRODUCTION

A perfect resistor would have zero phase-angle when used with alternating current and would show the same resistance to direct and alternating current. There are inevitable departures from this ideal in any practical resistor and a knowledge of the extent of these is often required. The present paper describes methods which have been used or developed at the National Physical Laboratory to determine the imperfections of resistors at power and audio frequencies. Most of the methods have been in use for a number of years and those that have already been described are therefore only treated briefly.⁽¹⁾

2. PROPERTIES OF RESISTORS

Every resistor has, in addition to its resistance, both inductance and capacitance, and while these will usually be mainly distributed quantities, it may safely be regarded for most purposes as a resistance R and an inductance L in series, with a capacitance C across the whole. The impedance of this network is

$$\frac{R + j\omega[L(1-\omega^2LC) - CR^2]}{1+\omega^2[C^2R^2 - 2LC + \omega^2L^2C^2]} \qquad (1)$$

Since in a well-designed resistor, within its normal frequency range, R is necessarily much greater than ωL and much less than $1/\omega C$, the impedance is approximately given by $R + j\omega(L - CR^2)$; the reactive part of this may be expressed in terms of an equivalent inductance, $L_e = L - CR^2$, or of an equivalent shunt capacitance $C_e = C - L/R^2$. Alternatively the impedance may be expressed as $R(1 + j\omega\tau)$, where τ is the time constant and is equal to $L/R - CR$ approximately.

In the case of four-terminal resistors the impedance is the quotient of the voltage at the potential terminals by the current at the current terminals. With a well-designed resistor of about 10 Ω or more, there should be no sensible difference in the value of the time constant whether it is a two-terminal or four-terminal instrument.

With two-terminal resistors below 10 Ω it is usually convenient to express the phase defect in terms of the inductance, since the uncertainty, both in the value and its measurement, arises from the inevitable uncertainties associated with small inductances; for higher values the accuracy is limited by uncertainties arising in the resistors used as standards of time constant and in the measuring techniques, and the errors in time constant are roughly constant for resistors up to 10 000 Ω. Thereafter the uncertainty in the shunt capacitance will usually predominate, unless the resistor has an independent screen and it is used in a circuit that enables the admittances between the screen and the resistor terminals to be eliminated. The effects of distributed capacitance are considered later.

In four-terminal resistors the uncertainty in inductance will depend upon the magnitudes of stray mutual inductances between the current and potential circuits; by avoiding inductive loops in these and separating the current and potential terminals, the mutual inductances can be kept low. It is found with four-terminal resistors of good design that the accuracy with which the time constant can be defined and measured does not worsen greatly as the resistance is reduced.

The time constant of resistors less than 50 Ω in value is usually inductive and that of resistors above 100 Ω is usually capacitative; with resistors of intermediate value the inductance and capacitance compensate one another and the time constant is about zero. From considerations of the size of small resistors of the carbon composition type for use at radio frequencies, it is to be expected⁽²⁾ that the time constant will be zero for values around 30 Ω; this is found to be the case.

The effective series resistance of a circuit element carrying alternating current may be different from the value obtained with direct current because of either skin effect in the conductors or shunt capacitance. At the frequencies under consideration, eddy currents are only likely to cause significant changes—that is to say changes of the order of 1 part in 10^4—in resistors of low value designed for large currents in which the conductors must necessarily be of large cross-section; changes due to capacitance will only become appreciable for the larger values of resistance and at the higher frequencies, as the denominator of equation (1) departs significantly from unity. In these cases, it should be remembered that the effective resistance cannot in general be calculated from the equivalent shunt capacitance, since the total capacitance may be considerably greater than this and partly compensated by an inductive winding of the resistor. Moreover, if both the inductance and capacitance are large, the fact that they are distributed quantities cannot always be ignored at the higher frequencies and the resistor may have to be regarded as a transmission line for analytical purposes.⁽³⁾ If R, L and C are the totals of uniformly distributed resistance, inductance and capacitance the impedance is, approximately:

$$Z = R\left[1 + \omega^2\left(\frac{2}{3}LC - \frac{2}{15}C^2R^2\right)\right] + {} + j\omega\left[L + L\omega^2\left(\frac{1}{3}LC - \frac{2}{5}C^2R^2\right) - \frac{CR^2}{3}\right] \qquad (2$$

ther the effective resistance and inductance increase or ease with frequency will depend upon the relative magles of R, L and C. For zero time constant at low iencies $L = CR^2/3$, when

$$Z = R\left(1 + \frac{4}{5}\frac{\omega^2 L^2}{R^2}\right) - j\frac{13}{5}\frac{\omega^3 L^3}{R^2} \qquad (3)$$

distributed capacitance may be composed of capacitances een one part of the resistor and another, and, if the tor is within a screen connected to it, of capacitances to creen.

circuits in which the screen is not connected direct to resistor but to earth, as for example may be the case in idge with Wagner earthing arms, a distributed earth citance will be introduced; this has an effect on the t impedance between the resistor terminals that is rent from the case considered above, and the direct dance is approximately given by

$$R\left[1 - \omega^2\left(\frac{1}{3}LK + \frac{K^2R^2}{120}\right)\right] +$$

$$+ j\omega\left[L - L\omega^2\left(\frac{1}{6}LK + \frac{K^2R^2}{40}\right) + \frac{KR^2}{6}\right] \qquad (4)$$

e K is the total, uniformly distributed earth capacitance, the distributed self capacitance C is zero. It will be seen the capacitance K introduces a positive time constant, this effect may be used to obtain a zero time constant, by adjusting the value of K the negative time constant ed by the self capacitance C of the winding can be pensated.

RESISTORS AS TIME-CONSTANT STANDARDS

l determinations of the imperfections of resistors must be d on standard resistors of known properties; these may the form of resistors the properties of which can be ılated or the imperfections shown to be negligible within required range of frequencies: sometimes it may be ible to use a variable resistor which has an inductance is not known in value but is independent of the resistance. surements of the change of resistance with frequency are lly based on resistors which, from a consideration of design, are known to be substantially free from such ges below some particular frequency.

the N.P.L. two-terminal resistors of calculated inductance available from 100 to 10 000 Ω.(4) The range 100 to Ω is covered by a set of ten concentric resistors of 100 Ω h can be connected in series as desired; the decade to 10 000 Ω comprises ten individual resistors that have ıoid windings and are shielded. The inductance and citance have been calculated for each of the resistance es of the two decades and the time constants thus obtained an uncertainty estimated not to exceed 0·002 μH/Ω.

ie 1 Ω standard which provides the basis for measures on four terminal resistors has also been described in 1.(5) It comprises twenty-one bifilar loops of fine tance wire connected in parallel, and the inductance and citance of the network have been computed; capacitance ı appropriate amount has been connected in parallel to ce the time constant to zero within the estimated limits ncertainty which are ±0·0005 μH/Ω. It is estimated the resistance is different from the d.c. value by only parts in 10^4 at 1 Mc/s. The older standards, which this ced, were two, each of 1 Ω, that had 0·001 in. thick ca strip doubled-back to form a bifilar loop with a separator of 0·001 in. mica; it was calculated that within ±0·001 μH/Ω these also had zero time constants. Comparisons between these three resistors were consistent to 0·001 μH/Ω, and they place this class of measurement on a very secure foundation.

The type of variable resistor that has the greatest constancy of inductance is a straight uniform conductor made up of two wires of the same diameter but with widely differing resistivities, butt-jointed together and mounted between two rigid supports separated by the length of one of the wires; it is so arranged that the composite conductor can be moved axially between the supports to change the resistance without in any way altering the current path; hence the inductance remains constant, provided that the frequency is either low enough for the current distribution to be uniform in both wires or high enough for the current to be sensibly only on the surface of both wires.

Such a device is not convenient for ordinary use, but it provides a valuable check on the variation of inductance of variable resistors designed to have negligible changes of inductance. For instance, a 1 Ω constant-inductance slide-wire, of Campbell's design, was found to have an 0·010 μH increase in inductance between the extreme settings.

For resistance values greater than 1 Ω it is scarcely practicable to have a straight conductor, and for resistances up to 100 Ω a more compact arrangement must be adopted. At the N.P.L. two resistors are used, one of 10 Ω with 1 Ω increments and the other of 100 Ω with 10 Ω increments; the design of these is due to Astbury. Each instrument consists of ten V-shaped loops of copper wire and ten of eureka wire of the same diameter, with terminals at the end of each loop as shown in Fig. 1. A rigid bar enables external connexion to be made to any ten loops without appreciable alteration to the geometry of the circuit, apart from accidental irregularities that are present in the resistors themselves. Using the two resistors in series any change of resistance up to 100 Ω, in 1 Ω steps, is available with an inductance which does not vary by more than 0·005 μH or without an uncertainty in time constant of more than 0·002 μH/Ω, whichever is the greater.

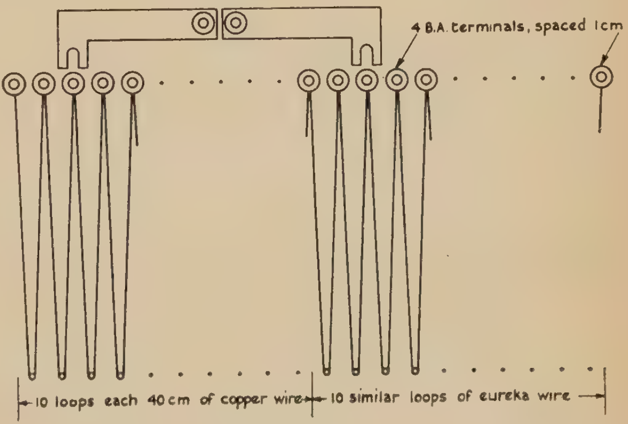

4 B.A. terminals, spaced 1cm
10 loops each 40cm of copper wire
10 similar loops of eureka wire

Fig. 1. Circuit diagram of N.P.L. constant-inductance resistors

4. FREQUENCY VARIATIONS OF RESISTANCE

Standards for the measurement of the change of resistance with frequency can readily be obtained by using wires which are thin enough to have negligible skin-effect within the power and audio-frequency ranges and by winding the wire so that the inductance and capacitance are kept small. A nickel–chromium–aluminium alloy is particularly suitable as its high resistivity and low temperature coefficient enable a small resistor with a high current rating to be used. (The magnetic permeability of a sample of such an alloy was found to be less than 1·01.) In order to minimize the inductance the wire should be wound on a thin, stable former that is made of a material of good dielectric properties; mica is very suitable as it is mechanically rigid and has a low power factor; if necessary, polythene tape may be used as a "cushion" to prevent the sharp edges bending the wire too severely. The capacitance may be reduced by spacing the turns of wire either in groups, or, what is more effective, by spacing each turn from the adjacent ones.

5. MEASUREMENT OF THE TIME CONSTANT OF POTENTIAL DIVIDERS

A Kelvin–Varley potential divider is used in many of the networks described below, and it is convenient therefore to consider first measurements on the time constant of potential dividers. In a potential divider, such as that comprising R_3 and R_4 in Fig. 2, the quantity required is either the difference of time constant, $\tau_4 - \tau_3$, of the resistances R_3 and R_4, or the difference between the time constant τ_T of the complete resistance and the time constant of either section of it. The relation between these quantities is given by the expression

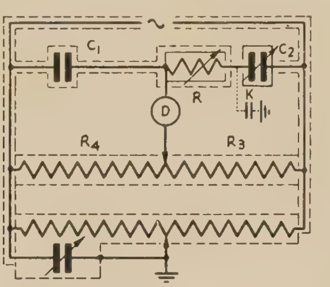


Fig. 2. Measurements on potential dividers
Wagner arms shown unmarked.

$$(\tau_T - \tau_3) = (\tau_4 - \tau_3)R_4/(R_4 + R_3) \qquad (5)$$

(*a*) *Capacitance-resistance bridge.* The network used for determining the time constant difference of potential dividers is essentially a capacitance bridge in which the divider forms arms 3 and 4, as shown in Fig. 2; a small resistance R in series with one of the capacitors provides the necessary phase-adjustment. At balance the relation between the time constants of the arms of the bridge is

$$\tau_4 - \tau_3 = (\gamma_1/\omega) - (\gamma_2/\omega) - R(C_2 + K) \qquad (6)$$

where γ_1 and γ_2 are the power factors of the capacitors C_1 and C_2 and K is the capacitance to earth from the junction of C_2 and R. Capacitance arms are chosen for this bridge since it is possible to determine with high accuracy the difference of power factor of two capacitors having widely different capacitance values.$^{(6)}$

To achieve high precision in measurements on this bridge care is necessary in the choice of the components, and in their disposition to avoid stray capacitances. When an unscreened divider is under test this is particularly important because the effect of distributed capacitance is not eliminated by a Wagner earthing network. The capacitance K should be small and definite; thus when a three-terminal capacitor is used for C_2, the terminal with the smaller earth capacitance should be connected to R, and if a two-terminal capacitor is used the insulated terminal should be connected to R. The resistor R should be doubly screened, with the inner screen connected to the end of the bridge arm and the outer screen earthed. The inner screen ensures that the only earth capacitance is to the detector terminal, while the outer screen eliminates cross capacitances$^{(7)}$ to other parts of the network. The uncertainty in the value of K is then reduced to the earth capacitance of the short length of lead connecting C_2 and R, which may be left unscreened. All other connecting leads should be screened.

The selection of the capacitors C_1 and C_2 involves a compromise. Air capacitors having negligible power factors are, on this account, preferable, but their use will make the impedance of these arms of the bridge high and it may be difficult to obtain sufficient sensitivity; also, their relatively small capacitances will make an accurate knowledge of K correspondingly important. On the other hand, the use of large mica capacitors would demand a knowledge of the value of R, which must include the resistance of connecting leads and terminal contacts, to an accuracy that it is impossible to attain. With a capacitor of 0·1 μF, resistance settings to 0·01 Ω will give an accuracy of 0·001 μH/Ω on the time constant, and this is a reasonable maximum value of capacitance to choose. The effect of leads resistance in both capacitance arms of the bridge must, of course, be allowed for.

The Kelvin–Varley potential divider in use at the N.P.L. has been calibrated by this method: the results obtained agree to ±0·002 μH/Ω on time constant with those obtained by direct comparison with the standard resistors of calculable reactance, which is the estimated uncertainty in the value of these standards. The divider is therefore a substandard which may be used to calibrate any other potential divider.

(*b*) *Bridge with four resistive arms.* Low resistance potential dividers, which cannot readily be measured on the capacitance bridge described above, may be calibrated against the substandard Kelvin–Varley divider by forming a resistive four-arm bridge with a capacitor across one of the arms to provide a quadrature adjustment. If arms 1 and 2 contain the divider under test and arms 3 and 4 the substandard divider, with a capacitor across arm 4 ,the form of the equation of balance is

$$\tau_1 - \tau_2 = \tau_4 - \tau_3 - CR_4 \qquad (7)$$

If, as in this case, the capacitor C is across a part of the Kelvin–Varley divider, the observed value of CR_4 must be corrected for the resistance S which is effectively in series with the potential connexion because the divider is not a simple tapped resistor. The derivation of the correction is given in the Appendix and the accurate equation of balance is

$$\tau_1 - \tau_2 = \tau_4 - \tau_3 - CR_4[1 + S(1/R_4 + 1/R_3)] \qquad (8)$$

6. MEASUREMENTS ON TWO-TERMINAL RESISTORS

(*a*) *Resistors greater than* 10 000 Ω. The bridge in Fig. can be used to measure the time constant of a resistor if arms 3 and 4 are comprised of the unknown and a standard of known time constant; it is most suitable for large values of resistance.

The effective shunt capacitance of large value resistors can also be obtained by observing the effect of connecting the test resistor in parallel with one arm of a bridge network. A Schering bridge may be used for resistors of about a megohm.

upwards; if capacitors, C_1 and C_2, and resistors R_3 and form the bridge arms, with a capacitor C_3 across R_3, the dge is first balanced to obtain readings C_{1b} and C_{3b}. The nown resistor is then connected in parallel with C_1, and econd balance made, giving readings C_{1a} and C_{3a}. The ctive shunt capacitance of the unknown is

$$C_{1b}/(1 + \omega^2 R_3^2 C_{3a}^2) - C_{1a} \tag{9}$$

resistors with values in the region of 100 000 Ω a four- resistance bridge with capacitance across one arm may used. Let R_1 be a known resistance with a capacitance C_1 parallel with it, R_2 a resistor of known time constant τ_2 R_3 and R_4 the Kelvin–Varley divider. The test procedure s before, with readings of the capacitor and divider taken ore and after connecting the test resistor across R_2. The nt capacitance, C_x, of the test resistor is given by

$$= [C_{1a} - C_{1b} + (\Delta_a - \Delta_b)/R_1]n_a - (n_a - n_b)\tau_2/R_1 \tag{10}$$

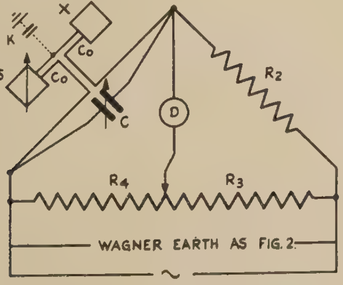
ere $n = R_4/R_3$, and $\Delta = \tau_4 - \tau_3$ is the time constant erence of the divider.

b) *Resistors between* 100 *and* 10 000 Ω. The time constant a resistor in the range 100 to 10 000 Ω is measured at N.P.L. by substitution with an appropriate standard of culated inductance, using a four-arm resistance bridge h a parallel capacitance. Arms 3 and 4 are formed by Kelvin–Varley divider, arm 1 is a known resistance with apacitance C in parallel, and the standard and test resistors connected successively into arm 2. Using the notation ove, with subscripts s and x for the standard and unknown pectively, we have

$$\tau_x = \tau_s + (C_s - C_x)R_1 + (\Delta_s - \Delta_x) \tag{11}$$

ien the test and standard resistors are of the same nominal ue the last term is usually negligible as only a small change he divider setting will be required. If there is a difference the value of the two resistors, the value of R_1 should be osen to restrict the change of the setting of the divider to lower dials and to avoid changing the highest dial when- r possible; this is because there is a considerable alteration the time-constant difference Δ when the setting of the hest dial is altered, whereas the alteration of Δ is small uniform for changes in the settings of the lower dials. example, Δ increases by about 0·01 μH/Ω between the ings 499·99 and 500·01, and by the same amount between 0·01 and 499·99. This is a point of general application he use of the divider in bridge networks.

c) *Resistors between* 1 *and* 100 Ω. The residual inductance a resistor in this range is measured against a constant- uctance resistor using the network of Fig. 3. The constant-inductance and test resistors are connected in series in arm 1; a twin-flex lead in the form of a symmetrical T is used to connect the resistors to the bridge points, thus ensuring equality of the capacitances across the resistors. Arm 2 contains a known resistance and arms 3 and 4 consist of the Kelvin–Varley divider. A variable capacitor is required across one arm of the bridge, and since the constant-inductance resistor has appreciable inductance, arm 1 is the most convenient. The bridge is first balanced, with the constant-inductance resistor at its minimum setting and the test resistor in circuit, by adjusting the divider and the capacitor; the leads to the test resistor are then short circuited, preferably on to one of its terminals to cause the least disturbance in the geometry of the circuit, and a second balance is obtained by adjusting the constant-inductance resistor and the capacitor. In this second balance it is usually easier to reach the final stage by adjustment of the divider instead of the resistor—the subdivision is finer and there is no trouble from variable contact resistance; no error is introduced if only small changes in the setting of the divider are made. If the capacitor readings for the two balances are C_x and C_s, the residual inductance L of the test resistor is:



ig. 3. Measurements on two-terminal resistors less than 100 Ω

X, test resistor; *S*, constant-inductance resistor.

$$L = (R_2 R_4/R_3)^2 (C_x - C_s) \tag{12}$$

The finite resistance R_0 of the constant-inductance resistor at the minimum setting prevents true symmetry in the substitution between it and the test resistor R_x, and introduces two possible sources of error. If, owing to the two branches of the flex-lead, there is a capacitance C_0 across the constant-inductance resistor and the test resistor, the measured inductance is too great by 2 $R_0 R_x C_0$. In addition, there may be an earth capacitance K from the junction of the two resistors; this again makes the measured inductance too large by $R_0 R_x K$. Both these errors are readily kept negligible, but they must not be ignored; for example, the residual inductance of the various settings of ×10 Ω decade dial should not be measured by taking settings of 0, 10, 20 . . . Ω with the constant-inductance resistor set at 100, 90, 80 . . . Ω; each setting must be treated as an individual measurement as outlined above.

The principle of substituting for the unknown resistor an equal change in a constant-inductance resistor may be applied to other networks suitable for measuring inductance changes; the Campbell–Heaviside bridge is such a one. It has the disadvantages, however, that with values of resistance at the higher end of the range, the additional stray capacitances may introduce errors, and also that additional readings may be required since reversals of the components will sometimes be necessary to eliminate the effects of unwanted mutual inductances.

(*d*) *Resistors below* 1 Ω. A constant-inductance variable resistor in an arm of a bridge introduces an undesirable contact, which by its nature tends to be unsteady and makes it difficult to obtain a balance, particularly when measuring small resistances. Fortunately, when measuring resistances within this range it is possible to dispense with a constant-inductance resistor and, although this introduces a correction for the inductance in the bridge arms, to maintain sufficient accuracy. The bridge circuit is shown in Fig. 4; the test resistor, R, is in series with a parallel combination of a fixed resistor R_1 and a capacitor C_1 in arm 1; arm 2 contains a resistor of known inductance across which a small, known capacitor may be needed, giving an impedance of $R_2 + jX$ in the arm. As before, arms 3 and 4 are formed by the Kelvin–Varley divider. The bridge is first balanced with the test resistor short circuited and then with it in circuit; if the subscripts b and a, respectively, are used for the pairs of capacitor and divider settings, the inductance is given by:

$$L \simeq R_1^2(C_{1a} - C_{1b}) + R_1(\Delta_a - \Delta_b) + R\Delta_a + L_2(n_a - n_b) \quad (13)$$

where $\Delta = \tau_4 - \tau_3$, $L_2 = X/\omega$ and $n = R_4/R_3$; terms in ω^2 have been omitted as these are usually small at audio frequencies.

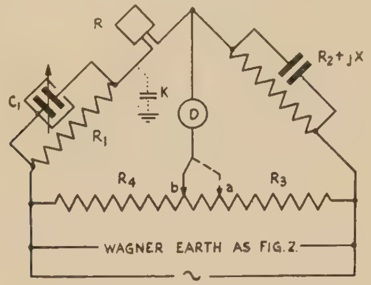


Fig. 4. Measurements on two-terminal resistors of low resistance

R, test resistor.

An earth capacitance K at the junction of R and R_1 is again a possible source of error which will make the measured inductance too great by RR_1K. The second, third and fourth terms in equation (13) are small and dependent on the relative values of R and R_1; it is unwise to increase R_1 in order to make them negligible as this will introduce other uncertainties, such as that due to K, and a value of about 10 Ω for R_1 is reasonable. The value of L_2 can usually be estimated with sufficient accuracy; if necessary, it may be measured by taking similar readings with a resistor of constant or known inductance in place of the test resistor, and solving the above equation for L_2.

7. MEASUREMENTS ON FOUR-TERMINAL RESISTORS

(*a*) *Hartshorn's method.* The adaptation of the Kelvin double bridge for the measurement of time constant has been described by Hartshorn;$^{(8)}$ it is a method particularly suitable for resistors of 1 Ω and under. The network is a six-arm bridge as shown in Fig. 5; in this the auxiliary arms 5 and 6 form a potential divider which ensures that the detector is effectively connected to a point at an appropriate potential between the adjacent potential tappings of the resistors R_1 and R_2. It is convenient, but by no means essential, to reproduce in arms 5 and 6 the resistance values in arms 4 and 3; doing so simplifies the bridge equation and this condition is assumed below. Arms 3 and 4 consist of the Kelvin–Varley divider; arms 5 and 6 should be screened resistors capable of fine adjustment and placed near the divider so that any open loops in the connecting leads to these four arms are minimized. The four-terminal resistors, R_1 and R_2, should be separated sufficiently from the other arms to avoid inductive coupling and, for the same reason, a twisted-pair lead should be used to connect the potential terminals of each resistor with the other arms. The current terminals of the two resistors should be close together and the connecting lead II' of low resistance; the loop formed by the current circuit should be as small as possible. Capacitors to provide the quadrature adjustment are required across two arms, say 3 and 6 as shown. The procedure is balancing the bridge is as follows.

(i) With the supply leads on AA' balance the bridge b adjusting C_3 and the ratio R_3/R_4, arms 6 and 5 being set to the same ratio.

(ii) Open the connexion between II' and balance b adjusting R_6/R_5 and C_6.

Repeat (i) and (ii) until the bridge is balanced with the link I both in and out; let the readings of the capacitors be C and C_{6a}.

(iii) Transfer the supply leads from AA' to BB', open th connexion II' and rebalance by adjusting R_3/R_4 and C let the reading of the latter be C_{3b}. The purpose o this additional observation is to allow for the mutua inductance in the leads from each of the four-termina resistors.

The difference of time constants is given by:

$$\tau_1 - \tau_2 = \tau_4 - \tau_3 + R_3(C_a + C_b)/2 \quad (14$$

The term involving R_3 must be corrected for the serie resistance S of the divider's potential connexion. This co rection may be avoided by a modification due to Rayner, which a capacitor C_1 is connected across arm 1 instead the capacitor across R_3, and in which in the final balance (i the capacitor C_6 is adjusted instead of C_3. If the reading a balance is C_{6b}, then

$$\tau_1 - \tau_2 = \tau_4 - \tau_3 + R_1C_1 + R_6(C_{6a} - C_{6b})/2 \quad (15$$

A large value will usually be required for C_1 and a 1 μ adjustable capacitor is suitable.

It may be noted that if the ratio R_6/R_5 is not continuou variable, it is permissible when obtaining balance (ii) abov to make a small change in R_3/R_4 and by this means to obt an accurate setting of C_6.

In arranging the connexions of this, or any low impedanc bridge, leads common to the supply circuit and Wagner arr should be avoided and independent leads should be take from the Wagner arms to the junction of the supply lea and bridge components, as indicated in Fig. 5. This simpl precaution will assist the attainment of simultaneous brid and Wagner balances.

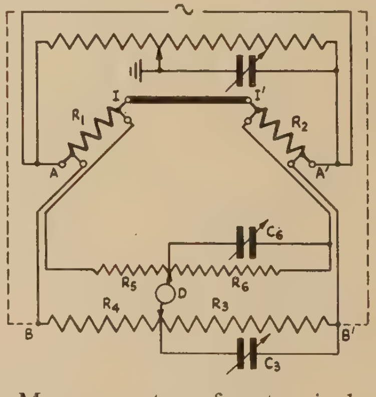


Fig. 5. Measurements on four-terminal resistors, Hartshorn's method

(*b*) *Arnold's method.* Heavy current shunts can be tested at power frequency by a method described by Arnold,$^{(9)}$ in which the standard and test resistors are compared in turn with a special dividing resistor; this resistor, the value of which is slightly more than 2 Ω, is subdivided into ten equal sections that are constructed to give the same time constant all settings. The standard resistor is chosen so that its istance ratio to the test resistor is 10 : n, where n is an eger between 1 and 10. The circuit is shown in Fig. 6; and R_x are the standard and test resistors, D is the dividing istor and T is a current transformer of suitable ratio. The tage across R_s is first balanced by adjusting the resistor P 1 the capacitor C; this is then repeated with R_x and the propriate fraction of D. Referring to the two balances by suffixes s and x, the difference of time constant is: $- \tau_s = D(C_s - C_x)$, where D is the total resistance of the cial divider.

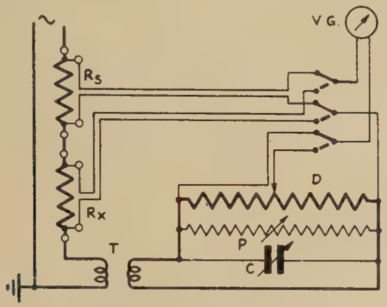


Fig. 6. Measurements on four-terminal resistors, Arnold's method

c) *Astbury's method.* Astbury has described a method(10) measuring the residual inductance of potential dividers 1 four-terminal resistors up to about 100 Ω in value; the asurement is based on a constant-inductance resistor tead of a resistor of known time constant, and the circuit shown in Fig. 7. The current terminals of the test resistor are connected between two fixed resistors R_1 and R_2 with onstant-inductance resistor R_c in series with R_1; a variable pacitor C is connected across R_1. It is convenient to use Kelvin–Varley divider for R_3 and R_4. A balance is first

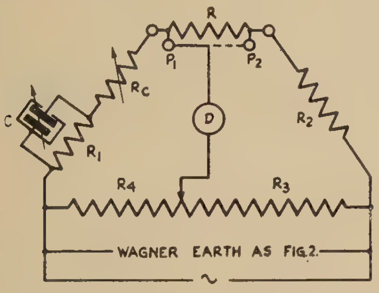


Fig. 7. Measurements on four-terminal resistors, Astbury's method

tained with the detector connected to the potential point p_1 adjusting R_3/R_4 and the capacitor, giving a reading C_1; detector lead is then transferred to p_2, with the least ssible alteration in the geometry of the circuit, and a cond balance obtained by adjusting R_c and the capacitor, ing a reading C_2. The residual inductance L of the test sistor is given by:

$$L = R_1^2(C_2 - C_1)R_3/(R_3 + R_4) \qquad (16)$$

Since the method depends upon the constancy of inductance R_c, which is rarely better than 0·002 μH and may be veral times worse, its accuracy for low resistance shunts is ferior to the previous methods.

The constant-inductance resistor may be dispensed with and both the balances obtained by adjusting the divider(11); the method then becomes very similar to that described in Section 6(*d*) for measuring two-terminal resistors of less than an ohm. Equation (13) for the inductance is the same except that, since the test resistor is in effect transferred from one arm of the bridge to the adjacent arm, the left-hand side becomes $L(1 + n_a)$ in place of L.

8. CHANGE OF RESISTANCE WITH FREQUENCY

An accurate comparison of the time constants of resistors requires a precise adjustment of the resistive balance, and consequently a number of the networks described above may be used to compare resistances over a range of frequencies. The bridges which included a constant-inductance resistor are unsuitable both because the standard itself is not free from frequency change and because it is not capable of sufficiently fine adjustment. In some of the methods described above the balance equations are shown as approximations; these equations are accurate for the lower frequencies, but they may be slightly in error at the higher audio frequencies, since terms proportional to the square of the frequency have been omitted; for example there should be a denominator $1 + (\omega R_1 C_{1a})^2$ in the first term, $R_1^2 C_{1a}$, of equation (13). In these methods it will usually be found that similar terms introduce a more serious uncertainty in the equation for the resistance and that, on this account, they are not suitable for measurements of the resistance change with frequency. The methods described in Sections 5(*a*), (*b*), 6(*a*), (*b*) and 7(*a*) may all be used for comparing the change of resistance with frequency, at least up to the limits of the audio range, provided that the components are themselves suitable for this range.

ACKNOWLEDGEMENTS

The work described has been carried out as part of the research programme of the National Physical Laboratory, and the paper is published by permission of the Director of the Laboratory.

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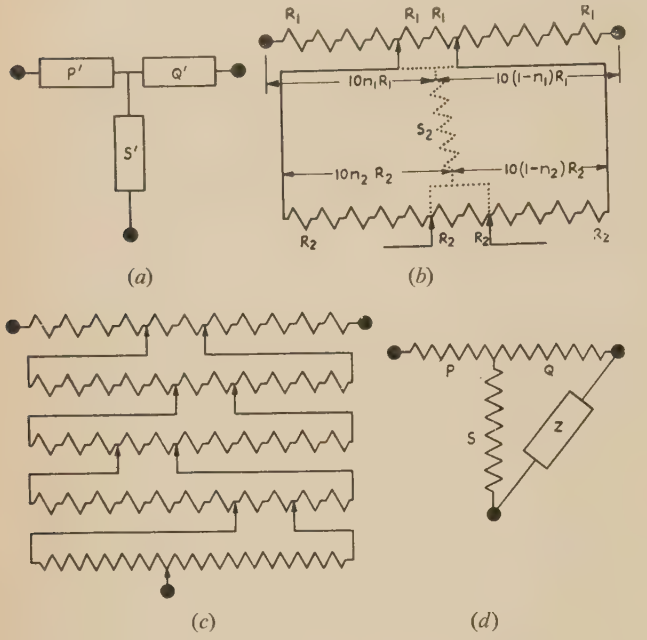
APPENDIX

Kelvin–Varley divider with shunt impedance

The network of a Kelvin–Varley potential divider with four dials and a slide-wire is shown in Fig. 8(*a*). First the transformation into the simple star network, Fig. 8(*b*), will be obtained, and then the effect of the shunt impedance, Z, will be considered and the equivalent star network, Fig. 8(*c*), given.

The effective series resistance, S, is not constant, but depends on the settings of the second and following dials.



(*a*) (*b*)

(*c*) (*d*)

Fig. 8. Kelvin–Varley potential divider

(*a*) Circuit diagram. (*b*) Equivalent network. (*c*) Equivalent star network. (*d*) Transformation of first delta.

Let R_1, $R_2 \ldots$ be the resistance per stud and n_1, $n_2 \ldots$ be the fraction of the voltage appearing at the detector terminals for the 1st, 2nd . . . dials of the divider, as indicated in Fig. 8(*d*). The resistance per stud of a dial is one fifth of that of the preceeding dial, i.e. $10R_2 = 2R_1$. Fig. 8(*d*) shows the first of the four Δ's which must be transformed into an equivalent star to obtain its contribution, S_2, to the total series resistance, S.

The usual Δ to Y transformation gives

$$S_2 = \frac{10n_2R_2 \times 10(1-n_2)R_2}{10n_2R_2 + 10(1-n_2)R_2 + 2R_1} \qquad (17)$$
$$= n_2(1 - n_2)R_1$$

Let the settings of the four decade dials and the slide-wire be a, b, c, d, and e for a divider of 1000 Ω total resistance; thus the instrument reading is $abc \,.\, de$, and $n_1 = 0 \,.\, abcde$, $n_2 = 0 \,.\, bcde$ and so on. The total series resistance is

$$S = S_2 + S_3 + S_4 + S_5$$
$$= n_2(1-n_2)R_1 + n_3(1-n_3)R_2 + n_4(1-n_4)R_3 + n_5(1-n_5)R_4$$
$$= 0\,.\,bcde(1 - 0\,.\,bcde)R_1 + 0\,.\,cde(1 - 0\,.\,cde)2R_1/10 + $$
$$+ 0\,.\,\mathrm{de}(1 - 0\,.\,de)4R_1/100 + 0\,.\,e(1 - 0\,.\,e)8R_1/1000$$
$$= bc\,.\,de(1 - 0\,.\,bcde) + 2 \times c\,.\,de(1 - 0\,.\,cde) + 4 \times$$
$$\times\, 0\,.\,de(1 - 0\,.\,de) + 8 \times 0\,.\,0e(1 - 0\,.\,e) \qquad (18)$$

The resistance P in the equivalent star network is, of course, $abc \,.\, de$ and Q is $1000 - P$.

A further transformation of the Δ formed by Q, S, and Z into a Y leads to the equivalent network of the shunted divider shown in Fig. 8(*c*). The effective ratio of the divider is found to be:

$$\frac{P'}{Q'} = \frac{P}{Q}\left\{1 + \frac{Q}{Z}\left[1 + S\left(\frac{1}{P} + \frac{1}{Q}\right)\right]\right\} \qquad (19)$$

In the bridge networks described above the shunt impedance is always a capacitor, and if $Z = 1/j\omega C$,

$$P'/Q' = (P/Q)\left(1 + j\omega CQ\left\{1 + S[(1/P) + (1/Q)]\right\}\right) \qquad (20)$$

In this case the term $S[(1/P) + (1/Q)]$ may be applied as a fractional correction to the capacitance C; the term may range from zero to about 0·1 for settings in the middle range of the divider, but it can be much larger at settings near either end. Tabulated values of S for the settings of the second and third dials, together with a table of the contribution of the fourth dial, enable an accurate and rapid estimation of S to be made; similarly the term $[(1/P) + (1/Q)]$ may be tabulated or obtained from a curve.

A photoelectric particle counter for use in the sieve range

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A photoelectric particle counter has been designed for the rapid measurement of the number of particles per gram in sieved fractions of opaque powders. The instrument can also be used for the determination of the size distribution of a powder in the sieve range in terms of numbers of particles.

INTRODUCTION

Photoelectric methods for counting particles in the sub-micron(1, 2, 3) and sub-sieve(4, 5, 6, 7, 8, 9) ranges have received considerable attention recently. The possibility of using such methods, however, for counting particles in the sieve range, say from 50 to 700 μ, has not been studied to any extent.

As part of an investigation of shape factors(10) we have recently found the need for a rapid routine method of determining the number of particles per gram in various sieved fractions of coke of size ranging from 60 μ to about 700 μ. The number of particles per unit weight is a quantity which also plays an important part in recent correlations(11) of the behaviour of fluidized beds.

Methods involving the automatic scanning of a slide upon which the particles were dispersed were considered. These were soon proved to be impractical because of the size of slide required for the coarser particles (e.g. 5000 particles of 500 μ diameter having one diameter spacing would require a slide 4 × 2 in.). It was decided to use a method in which the particles were moved in an orderly arrangement along a capillary. This was, in principle, very similar to the methods used by Gucker(1, 2) and by Crossland-Taylor(5) and had

advantage of not requiring a correction for boundary
rs.

DESCRIPTION OF EQUIPMENT

neral principle of operation. The particles were drawn spension along a capillary, so that they passed successively r the objective of a microscope and cut off the light from otomultiplier mounted above the eyepiece. The electrical lses produced were then amplified and counted ronically.

echanical arrangements. A diagrammatic representation own in Fig. 1. The capillary tube *B* was clipped rigidly o the microscope stage (rubber mounts being used to ce vibration) and connected by a spherical ground glass *D* to a receiver flask *E*. The bleeder valve *F* shown a small gate valve introduced into the pumping circuit nable the pressure drop across the capillary tube to be rolled. In the selection of a suitable capillary tube ieter, a lower limit was fixed by the requirement that icles should not jam in the tube and an upper limit by need to prevent particles moving in aggregates and the ability that a sufficient fraction of the available cross-on of the capillary should be obscured by the particle. rial, it was found that a convenient value of *R*, the ratio diameter/particle diameter, was about 5. Details of the s used are given in Table 1.

ne suspension was drawn through the capillary by partial uation of the receiver. The pressure drop had to be cient to give reasonable velocities through the capillary but not so large that the absolute pressure in the receiver became low enough for the liquid to boil. Limitations were thus imposed on the volatility and viscosity of the liquid. Also, the greater the density difference between the liquid and the powders, the greater was the rate of settling of the suspension. In order to prevent such settling, a simple paddle stirrer was used in the mixing chamber. The minimum possible degree of agitation to preserve homogeneity was used. More vigorous stirring caused air to be drawn into the suspension and to form bubbles at the low pressure end of the tube, particularly if surface-active agents had been added to the suspension to improve the wetting of the powders.

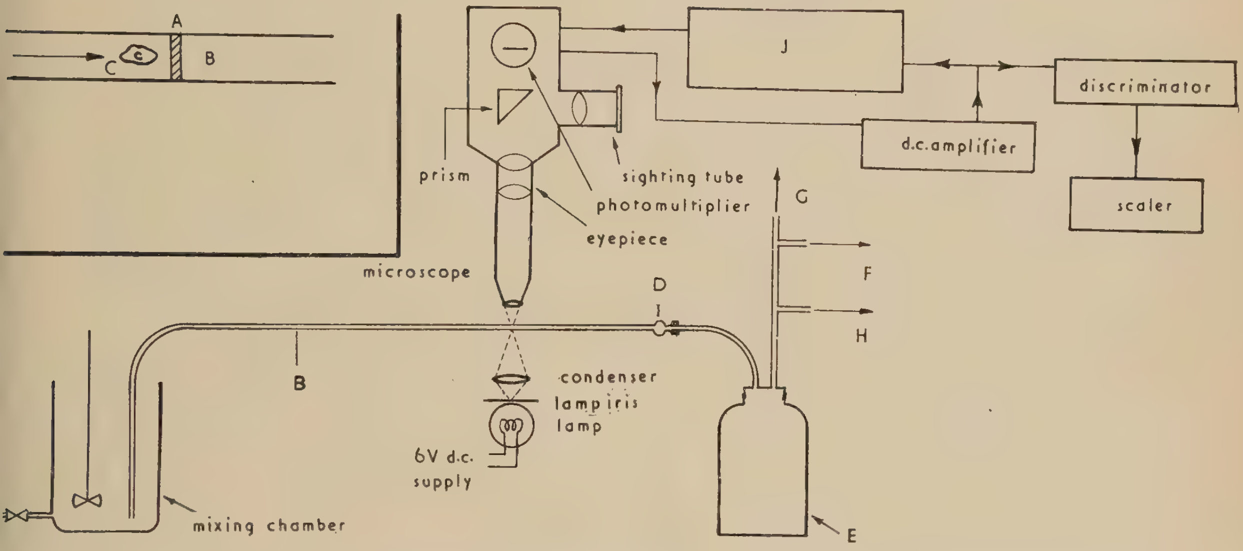

Fig. 1. Diagram showing optical and electrical arrangements

A, illuminated slit; *B*, capillary; *C*, particle; *G*, to vacuum pump; *H*, to manometer; *J*, automatically controlled h.t. supply for photomultiplier (see Fig. 2).

The liquids found to be most suitable were water, paraffin oil (Sp. gr. 0·835–0·850) and glycerol-water mixtures. These had refractive indices close enough to that of the glass to reduce spherical aberration to a tolerable level. The water, having a relatively low viscosity, was only suitable for use with the finest fractions. Paraffin oil was suitable for the intermediate sizes but not for the coarsest or finest fractions. Certain batches of paraffin oil were found to contain a considerable fraction of lighter oils which boiled off under reduced pressure, causing bubbling in the capillary. The glycerol-water mixtures met all the requirements and proved most suitable when used in the concentrations given in Table 1.

Optical arrangements. The microscope was focused on the median plane of the capillary. A small microscope lamp using a 6 V 30 W lamp supplied from an accumulator had

Table 1. *Conditions used for different sizes of particles*

Size grades S. test sieves	*Suspending media*	*Suspension concentration*	*Capillary diameter*	*Objective*	*Microscope Eyepiece*	*Magnification*	*R*
22 + 36	90% glycerol–10% water	8 g/litre	2 mm	50 mm	×6	10×	3·6
36 + 52	80% glycerol–20% water	7·5 g/litre	1·5 mm	50 mm	×6	10×	4·2
52 + 72	80% glycerol–20% water	7 g/litre	1 mm	32 mm	×6	25×	4·0
72 + 100	70% glycerol–30% water	6 g/litre	1 mm	32 mm	×6	25×	5·5
100 + 120	60% glycerol–40% water	4 g/litre	0·5 mm	32 mm	×6	25×	3·6
120 + 200	50% glycerol–50% water	4 g/litre	0·5 mm	32 mm	×6	25×	5·0
200 + 240	20% glycerol–80% water	3 g/litre	0·35 mm	16 mm	×6	65×	4·9

particles giving pulses greater than that voltage, i.e. the fraction oversize. The corresponding percentages oversize are plotted in Fig. 4.

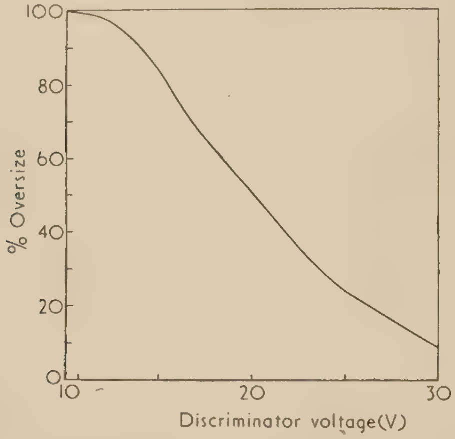

Fig. 4. Plot of percentage oversize against discriminator voltage for unclassified powders

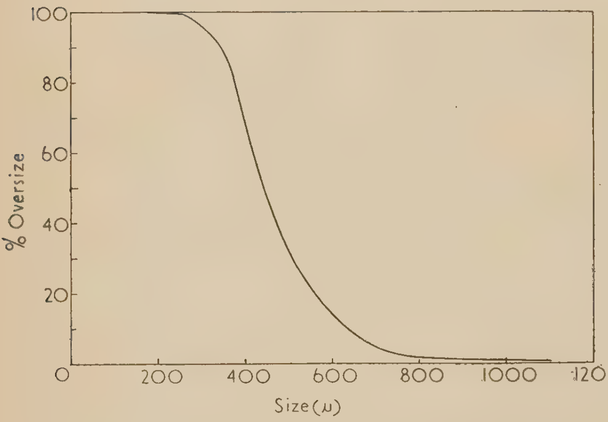

Fig. 5. Size distribution from microscope count

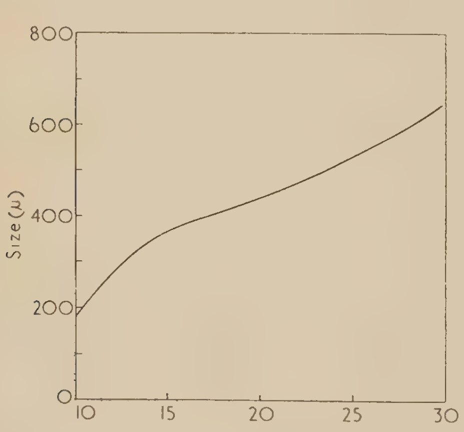

Fig. 6. Calibration curve of particle size against discriminator voltage

The size distribution of the suspension was determine conventionally using a microscope with a filar micromet eyepiece and plotted as a percentage oversize (Fig. 5). Cros plotting from Figs. 4 and 5 then gave a plot of discriminat voltage against particle size, shown in Fig. 6. This is th required calibration curve and with its aid, particle siz distributions, at least for similar powders, can be obtaine on other samples directly from counting rate-discriminat voltage curves. The calibration curve can be seen to b roughly linear over the range 300–600 μ.

This could form the basis of a very rapid method fo determining particle-size distributions on a number rath than a weight basis. If the particles can be assumed to b spheres or if a standard sphericity factor is known, th number distribution can, of course, be converted to a weig distribution. The main experimental difficulty would be t maintain a sufficiently homogeneous suspension. Even wi the controlled conditions of the test, fluctuations of ±10 in number of particles per unit volume of fluid were commo

ACKNOWLEDGEMENTS

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A synthesizer for triangular wave functions

y Prof. DAN MCLACHLAN, Jr., B.Sc., M.Sc., Ph.D., Stanford Research Institute, Menlo Park, California, U.S.A.

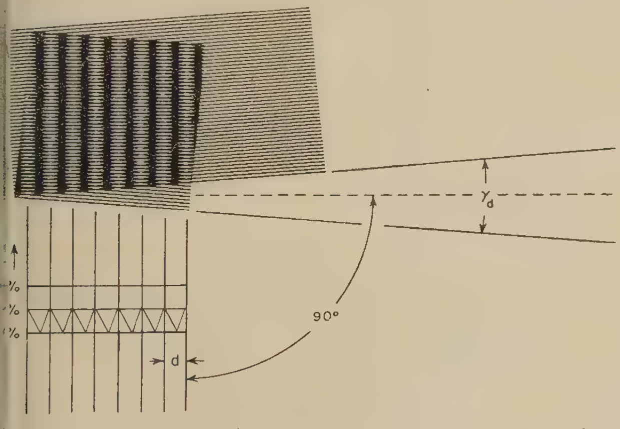
[*Paper received* 29 *November*, 1956]

This paper describes an optical analogue computer for summing the Fourier series necessary in computing electron densities of crystals from X-ray data. Aside from its cheapness and ease of handling, its main feature is that the patterns characteristic of the Bragg–Huggins masks are synthesized in the machine by turning a knob which turns in opposite directions two drums upon which are mounted sheets of banded transparent film. Since the projected patterns or fringes are very close to the photographic recording paper, the light scattering is slight.

of the earliest methods devised for the computation of tron densities in the unit cells of crystals from X-ray data that developed by Bragg(1) using photographic masks light and dark bands or "fringes" on them. The first mpt to make the Bragg masks available to X-ray workers ulted in the square masks of Huggins.(2,3) Later, Howell, istensen, and McLachlan(4) redesigned the masks to rove their reproducibility in manufacture. McLachlan Woolley(5) made a multiple projector to increase the speed ease of using the masks and Howell and McLachlan(6) roved the construction of the multiple projector so that ould be built as a table top model. At the same time, Eller(7) constructed an optical device for generating the ges during use. It was based upon the principle that the pacing in the fringes can be controlled by regulating the ance between the point source of light and the projection en. This ability to generate fringes at will is one charac- stic the von Eller device has in common with the instru- nt described herein.

lthough most of the attempts to improve the original gg masks resulted in genuine improvements, the multiple jectors have not produced pictures that are as clear as ne of the Bragg or Huggins pictures. This lack of clarity ue, in part, to the tendency of photographic emulsions to tter light as well as absorb it. There should be some antage in keeping the mask as close as possible to the ording photographic paper to reduce the scattering ance.

he purpose of this paper is to describe a device which duces a photographic representation of the electron sity on a plane of the unit cell (using short optical paths avoid the bad effects of scattering) and, at the same time, retains the compactness, speed, and freedom from the dark room claimed by other devices.



ig. 1. Two transparent masks, superimposed at angle $_d$, produce fringes having spacing *d*. The mean trans- parency plotted perpendicular to the fringes is a triangular wave

The two novel features of the instrument are: (*a*) instead of using as many masks as there are combinations of the desired Miller indices, the desired designs are produced at will by the counter-rotation of only two masks; and (*b*) the designs do not represent sinusoidal wave functions but triangular wave functions.

If a transparent film has imprinted upon it parallel black bands of about 1 mm width, spaced so that the distance *a* between them is equal to their width, then the average transparency is 50%. Such a film is shown in position in Fig. 1 and upon it at an angle γ_d is an identical film. Where the films overlap, the average transparency is 25%. The transparent regions are diamond shaped and are alined in rows and columns, giving the general appearance of a portion of a Bragg–Huggins mask. The spacing *d* between the columns can be adjusted at will by varying the angle γ_d according to the equation

$$d = (a \cos \tfrac{1}{2}\gamma_d)/(\tan \tfrac{1}{2}\gamma_d) \qquad (1)$$

Fig. 2 shows a representative graph of *d* plotted against γ_d when *a* is 0·5 mm.

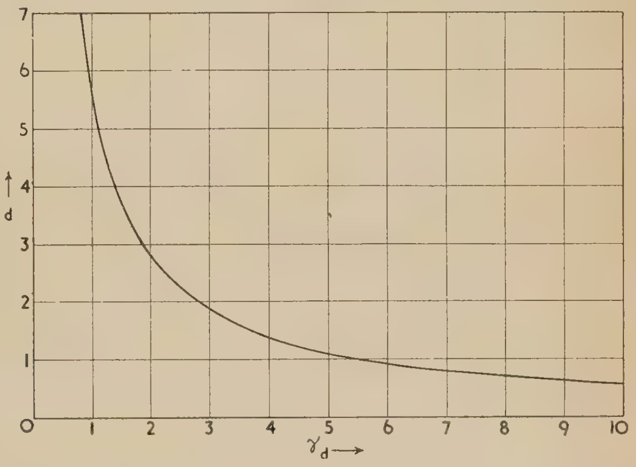


Fig. 2. The *d* spacing of the fringes as a function of the angle γ_d (see Fig. 1) using equation (1) when stripes on the masks have spacing 0·5 mm.

As shown in Fig. 1, a line bisecting the angle γ_d intersects the columns at right angles. Also the transparency *T* varies from 0–50% between columns in a triangular wave form instead of the usual sinusoidal wave form applicable to Fourier summations. The summation of triangular functions of *T* will be discussed later.

The apparatus for obtaining a triangular wave function of any d value, orientated at any ϕ angle, with any desired phase α, and photographing it for any length of time proportional to F_{hk} or T_{hk} is shown in Fig. 3. Two concentric cylinders or drums D_i and D_o are driven by two gears G and G'. When the knob K is turned the drums are rotated in opposite directions. One mask Z (see Fig. 1) is mounted on top of the inner drum and supported by a $\frac{1}{16}$ in. sheet of commercial plastic Lumarith (by Celanese Corp. of America), L while a second mask Z' is mounted on the underside of a second plastic sheet L' on the outer drum. Thus turning the knob K to the desired value γ_d produces the d_{hk} values. A standard Eastman 8 × 10 in. film holder (by Eastman Kodak Co.) is mounted $\frac{1}{8}$ in. above L'. It holds film F ready for use and stored film F', separated by the sector S, and covered by the removable shields C and C'. Light is supplied from a bulb in the bottom of the inner drum. Any phase α_{hk} can be obtained (by turning the handle H which slides the block M in the guides J) and read on the scale P. The orientation of the triangular waves with respect to the crystallographic x axis is accomplished by turning the entire apparatus on the turntable T, by amount

$$\psi = \text{arc cos } hd/a$$

After the settings γ_d, S_α, and ψ are made, then the timer is adjusted to give an exposure whose duration is a function of F_{hk}. Repeating this process until all the experimental F_{hk} values are used gives an electron density map on the photographic film in the holder.

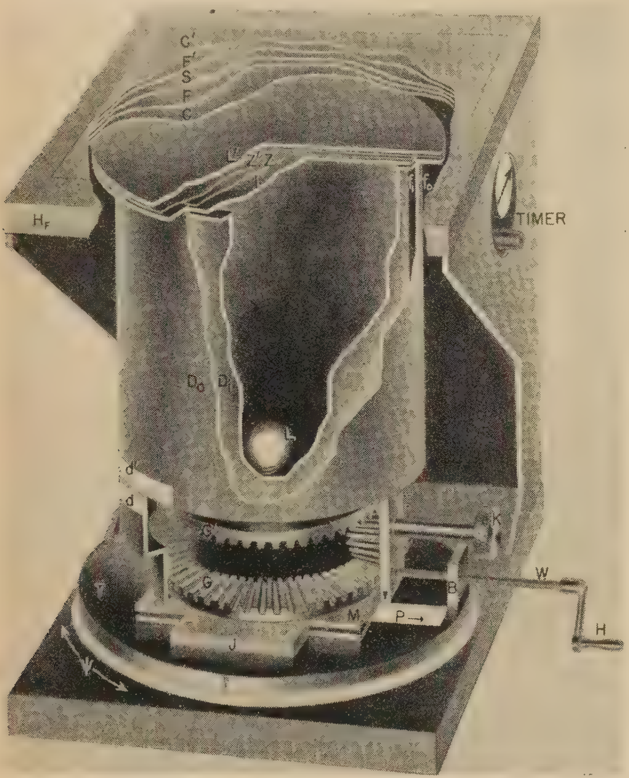


Fig. 3. The apparatus for producing and recording the triangular waves

A question arises as to how to make summations with triangular wave functions in a manner analogous to the summations proposed by Fourier with sinusoidal waves. Illustrating in one dimension, the usual Fourier summation is

$$\rho(x) = \sum_h F_h \cos\left(2\pi h \frac{x}{a}\right) \tag{2}$$

where

$$F_h = \frac{1}{a}\int_0^a \rho(x) \cos\left(2\pi h \frac{x}{a}\right) dx \tag{3}$$

In the use of triangular waves, a more complete discussion of which has already appeared,[8] F_h must be replaced by T_h and cos $(2\pi hx/a)$ by $C_\infty(2\pi hx/a)$,

$$\rho(x) = \sum_h T_h C_\infty\left(2\pi h \frac{x}{a}\right) \tag{4}$$

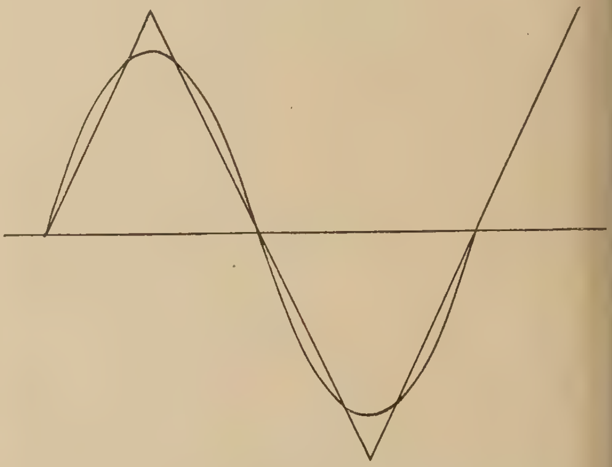


Fig. 4. A comparison of sinusoidal and triangular waves

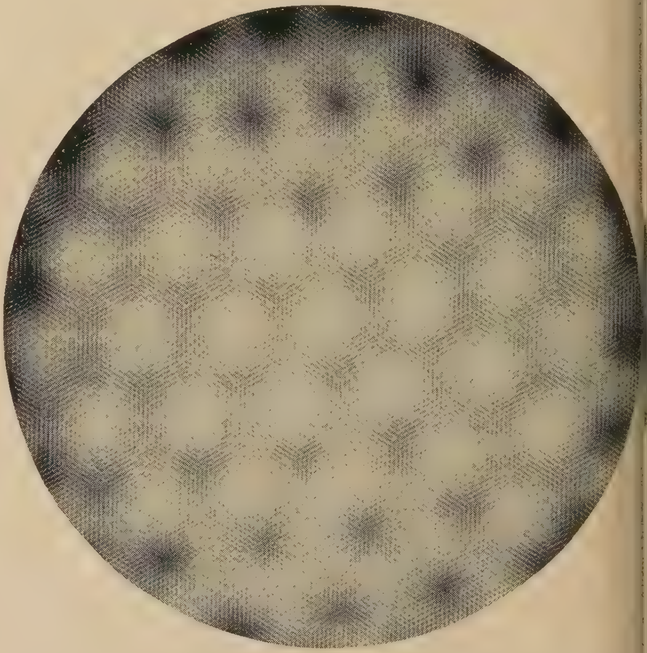


Fig. 5. Three exposures of equal spacing and duration, at angles 0°, 60°, and −60° produce maxima simulating the arrangement of carbon atoms in graphite

e C_∞ is related to the cosine function by the equation(9)

$$\pi h\frac{x}{a}\Big) = \frac{8}{\pi^2}\Big[\cos\Big(2\pi h\frac{x}{a}\Big) + \frac{1}{3^2}\cos\Big(2\pi 3h\frac{x}{a}\Big) + + \frac{1}{5^2}\cos\Big(2\pi 5h\frac{x}{a}\Big)x\ldots\Big] \quad (5)$$

T_h is related to F_h by the equation

$$T_h = \frac{\pi^2}{8}\Big(F_h - \frac{1}{3^2}F_{3h} - \frac{1}{5^2}F_{5h} - \frac{1}{7^2}F_{7h} - \ldots\Big) \quad (6)$$

$$1\cdot 234F_h - 0\cdot 137F_{3h} - 0\cdot 049F_{5h} - 0\cdot 0252F_{7h} - \ldots$$

terms and squared terms such as 9, 25, and 49 are ed).

shown in Fig. 4, the triangular wave approximates the e wave with varying accuracy, being 23·4% too high at eak and 8% too low at the second greatest deviation. imple structures, direct use of F_{hk} values in this apparatus t give satisfactory density maps, but the more compli- structures are certain to show ghosts.

show the interesting manner in which a triple exposure up the density to produce atom-like maxima, Fig. 5 s the result of three equally intense exposures of equal d s at $\psi = 0°$, 60°, and −60°.

garding the speed of the apparatus, a structure of 150 structure factors can be completed in about 1½ h. The need for operating in a dark room is removed by a black "bellows" connecting the drum D_o and the top frame H_F.

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Obliquity effects in interference microscopes

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A theoretical analysis is made of the influence of oblique rays on the fringes produced with interference microscopes. The convergency of the light, which is determined by the numerical aperture of the objective, results in the fringes being displaced from the position for ideally collimated light at normal incidence.

The analysis accounts fairly well for some recent measurements of step heights with microscopes of different numerical apertures by Tolman and Wood.(1) The correction due to obliquity is of the order of 10% and over a limited range of step heights, a simple correction rule of $\alpha 2/4$ per unit is satisfactory to about 2%, where $\alpha = \sin^{-1}$ (n.a.). The more rigorous formula shows a non-linear relation between obliquity-correction and step-height.

an and Wood(1) recently reported the measurement of height of stepped standards using different interference oscopes. The results were compared with those obtained a Kösters interferometer where the interference fringes ormed in collimated light. The strongly convergent light in the interference microscopes introduces obliquity ts, and the experimental work described was done in r to determine the correction factors for the microscopes, it was considered that theoretical computation was not ticable.

uce(2) and Thornton(3) recently reported the theoretical ysis of the effects of obliquity with particular reference nterferometers employing collimated light. This analysis icts very well most of the results of Tolman and Wood. a circular aperture, the analysis shows that the fringe lacement between fringes formed in perfectly collimated and those formed in light containing a range of slightly oblique rays is $(\Delta - n\pi)/2$, where Δ is the phase change across the diaphragm aperture in the optical system whose finite size determines the degree of obliquity, and

$$n\pi \leqslant \Delta \leqslant (n+1)\pi$$

If α is the maximum obliquity angle or angular aperture, $\Delta = K\alpha^2/2$ where $K = 2\pi t/\lambda$ or half the phase difference. If $\Delta < \pi$, the fringe displacement is $\Delta/2$ or $K\alpha^2/4$, and the fringe displacement due to obliquity is thus directly proportional to the phase difference (or path difference) and is given by $\alpha^2/4$ per unit.

The interference microscopes mentioned by Tolman and Wood are all based on the Michelson-type interferometer. In these instruments, the fringes formed over the top and bottom of the step arise from a path difference equal to the step height, if fringes are to be equally visible in both sets. For these conditions t is half the step height, and so for the measurements reported $0 \leqslant \Delta \leqslant \pi$, and the relative displacement of the two sets of fringes will be twice the displacement occurring for each set, since the direction of fringe order for one set is opposite to that for the other set. The numerical aperture of the microscope objective determines the degree of obliquity, and the maximum obliquity angle α will be $\sin^{-1}$ (n.a.), if the refractive index of the medium is taken to be unity.

Applying the simple correction rule of $\alpha^2/4$ per unit to the interference microscopes described, the correction factors have been calculated, and are shown in column 4 of the table. An observed step height must be multiplied by this correction factor to give the true step height. Column 3 shows the corresponding average experimental results stated by Tolman and Wood. Columns 5 and 6 give calculated values from relations derived by Gates[(4)] who averaged the simple obliquity effect for a point source over the angular aperture of the objective. Gates's equation (1) refers to results calculated from an expression which gives the value of the fringe spacing as

$$\frac{\lambda}{2}\left[1+\frac{\alpha^2}{4}+\frac{5\alpha^4}{72}+\frac{61\alpha^6}{2830}+\ldots+\frac{E_n\alpha^{2n}}{(n+1)2n!}\right] \qquad (1)$$

where E_n is an Euler number.

Gates' equation (2) refers to results calculated from an expression giving the value of the fringe spacing as

$$\frac{\lambda}{2}\left(\frac{ln \cos\alpha}{\cos\alpha-1}\right) \qquad (2)$$

Gates considers expression (2) is mote appropriate.

Obliquity correction factors for interference microscopes

Microscope	*n.a.*	*Correction factor* *Tolman and Wood (measured mean)*	*Bruce (1) and Thornton (1) calculated*	*Gates's equation (1) calculated*	*Gates's equation (2) calculated*
Hilger and Watts	0·65	1·12	1·12	1·15	1·14
Linnik–Zeiss	0·60	1·09	1·10	1·12	1·12
Hilger and Watts	0·30	1·03	1·02	1·02	1·02

The simple correction rule of $\alpha^2/4$ per unit comes from an analysis for collimated light systems in which the approximation $\cos\alpha = 1 - \frac{1}{2}\alpha$ was used. This approximation will be less accurate where α is relatively large, such as in the present case of a convergent light system. It is of interest to apply the method of analysis used for collimated systems to the present case, making no approximation for $\cos\alpha$. The intensity distribution I of the fringes for a circular aperture can be expressed as

$$I = A\int_0^\alpha \cos^2(K\cos\theta)\theta\, d\theta$$

where A is a constant,

K is half the phase difference,

and θ is the obliquity angle whose limiting value is $\alpha = \sin^{-1}$ (n.a.).

The condition for fringe maxima or minima is given by $\partial I/\partial K = 0$ and

$$\frac{\partial I}{\partial K} \propto \int_0^\alpha \frac{\sin(2K\cos\theta)}{\cos^2\theta}\sin\theta\, d\theta$$

Putting $\beta = 2K\cos\theta$

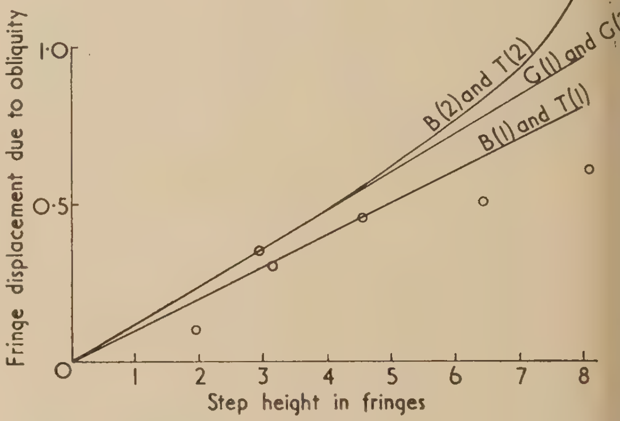
$$\frac{\partial I}{\partial K} \propto \int_{2K}^{2K\cos\alpha} \frac{\sin\beta}{\beta^2}\, d\beta$$

This integral is a standard one and it can be easily shown that

$$\frac{\partial I}{\partial K} \propto \frac{\sin 2K}{2K} - \frac{\sin(2K\cos\alpha)}{2K\cos\alpha} - Ci(2K) + Ci(2K\cos\alpha) \qquad (3)$$

where $Ci(2K)$ and $Ci(2K\cos\alpha)$ are cosine integrals whose values are available in tables for given values of the arguments $2K$ and $2K\cos\alpha$. Numerical evaluation of expression (3) gives the values of K for which $\partial I/\partial K = 0$, which can be compared with the values of K for $\partial I/\partial K = 0$ for a perfectly collimated beam ($K = \frac{1}{2}n\pi$ where $n = 0, 1, 2, \ldots$)

The fringe displacement curve due to obliquity calculated from expression (3) is shown in the figure for a range of ste heights, and for a microscope objective of n.a. 0·60, and i labelled $B(2)$ and $T(2)$. For comparison the curve calculated from expressions (1) or (2) is given, and is labelled $G(1)$ and $G(2)$. The curve calculated from the simple rule of $\alpha^2/4$ per unit is labelled $B(1)$ and $T(1)$. The experimental values obtained by Tolman and Wood are marked ○.



Fringe displacement curves due to obliquity for an interference microscope with an objective of n.a. =0·60

Expression (3) is, of course, valid for all values of K and α. In collimated light systems in which α is of the order of 10^{-3} radian, and where K is of the order of 10^6, the cosine integrals approach zero value and $2K\cos\alpha$ can be taken as $2K$. The condition for fringe maxima or minima is then given by

$$\sin 2K = \sin 2K\cos\alpha$$

$$= \sin(2K - K\alpha^2)$$

that is $K = \frac{1}{4}K\alpha^2 + \frac{1}{2}n\pi$

which is the condition established by Bruce[(2)] in the earlier work.

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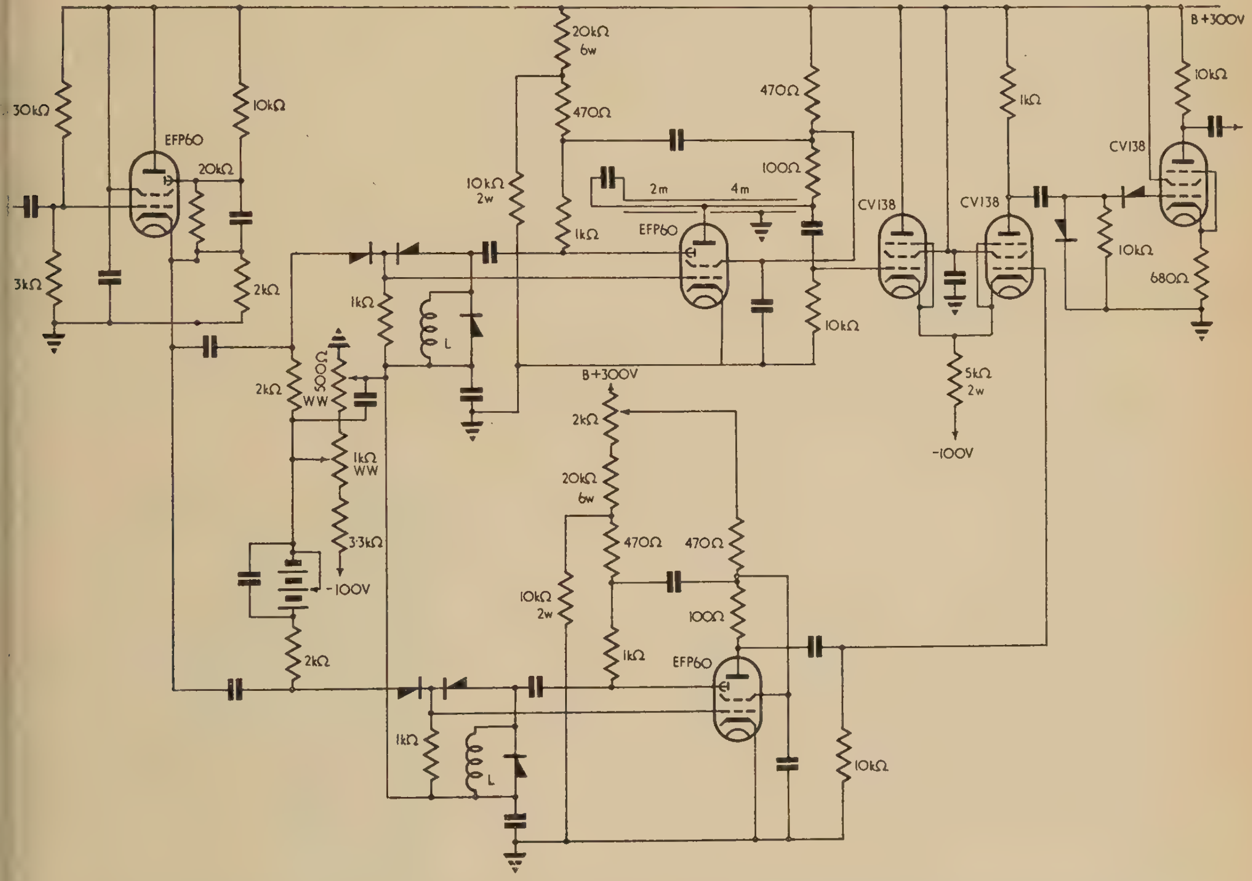
A fast kicksorter channel

By R. D. Amado, B.S., and R. Wilson, M.A., D.Phil.,* Clarendon Laboratory, Oxford

[*Paper first received* 26 *September, and in final form* 15 *November*, 1956]

A single channel kicksorter is described which responds to pulses as short as 10^{-8} s with a dead time of 10^{-7} s.

circuit for a fast kicksorter channel using type EFP60 s (by Mullard Ltd.) for triggers is shown in the figure. e triggers(1) have excellent response to fast pulses and a y sharp threshold. With pulses of 10^{-8} s duration there a uncertainty of less than 0·2 V in triggering threshold bias of 8 V. This causes reduced pulse height over the rtain range. For longer pulses the uncertainty is reduced.



Circuit diagram for fast kicksorter channel. All capacitors are 0·01 μF, and all diodes are germanium diodes

e is also a drift of about 3×10^{-8} s to earlier triggering he input pulse is increased from threshold. This drift rs only in the first 3 V of triggering for a bias level of and occurs without change in pulse height. Once the position is reached, the output changes no more with er inputs. The output pulse duration of the trigger is mined by the *LC* loop (*C* is the stray capacitance of the ctance and of the diode); an inductance of 3 μH is found to give an output 5×10^{-8} s long. An output pulse width of 2×10^{-8} s is the calculated minimum for such a trigger circuit.(2) The inductances are made of fine copper wire wound on a non-ferrous core. As long as care is taken that the input pulse duration is not longer than the dead time, it is found that with output pulses 5×10^{-8} s long, the dead time is about 6 or 7×10^{-8} s.

The 500 Ω rheostat provides a satisfactory operating point for the trigger valves together. A level of −3 V here usually gives good performance with Mullard EFP60 valves. The 1 kΩ rheostat provides the discriminator bias. Both sides of the channel are biased together by the rheostat giving an input pulse range of +5–+25 V. The channel width is determined by a dry cell battery with a switching system giving widths of 1·5, 3·0, 4·5, 6·0 and 7·5 V. These widths are stable to 3% or better. Since in practice it is found that the Mullard EFP60 valves used are sometimes as much as

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2 V apart in intrinsic bias level, two valves must be selected with less than 0·2 intrinsic bias difference by trial and error. It is desirable to have the difference less than 0·1 V, and hence an adjustment is included in the screen grid circuit of one of the valves. This 2 kΩ rheostat allows variations of screen grid voltage of 20 V, corresponding to 0·2 V swing in bias level. This insensitivity of bias level with regard to d.c. level changes beyond control grid is a reassuring test of bias stability.

The input to the kicksorter channel is first put through a cathode follower. Loading will occur through the input *RC* load of the triggers only if the diodes conduct. Since this will make loading dependent on bias level, loading must be substantially reduced to preserve linearity. The output of the cathode follower is fed to the two trigger circuits. The output of these is put through a standard "long-tail pair" anti-coincidence unit. A system of coaxial cables is used to shorten and to delay the output of the lower biased trigger. This system is used to correct for the triggering time difference between threshold triggering and "full-in" triggering. The condition for satisfactory coincidence blocking is that the pulse from the lower biased trigger occurs within the blocking pulse. This condition can be well satisfied by a delay cable 4 m long, a shortening cable 2 m long, and an inductance *L* in the trigger circuits of 6 μH. The delay cable need not quite the 3×10^{-8} s mentioned above because of roundi off of the pulses. The output of the anti-coincidence unit rather weak (about -1 V), so it is fed to a standard pento amplifier valve before being made available for countin The amplifier also converts to a positive output.

The diode linkage to the amplifier valve stretches th negative pulses (not the positive pulses introduced by th shortening cable) from the anti-coincidence set to the amplifie This stretches the output to a pulse of 10 μs duration, whic is amplified to a pulse height of +25 V. It should be note that the stretching does not affect the ordinary dead time the circuit. The dead time for random pulses is still determined by the *L* of the trigger circuit and is therefore of orde 10^{-7} s. Only the channel dead time is affected by the stretching to 10 μs.

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Laboratory and workshop notes

A precision electron-beam oscillograph with a spot diameter of a few microns

By Prof. M. von Ardenne, Forschungsinstitut, Dresden-Weisser Hirsch, DDR.

[*Note received* 8 *June*, 1956]

The precision electron-beam oscillograph* constitutes a development of the electron micro-oscillograph described during 1939.† The principle of the earlier micro-oscillograph was that the oscillogram of microscopically small dimensions was "written" by means of an extremely small electron spot, and then evaluated with the aid of a measuring microscope. In the case of the precision electron-beam oscillograph the extremely small electron spot is retained, but the oscillogram is no longer microscopically small but is "written" with the usual oscillographic amplitudes, using internal photography on 9 × 12 in. photographic plates. In the case of the normal commercial electron-beam oscillographs, the ratio of spot diameter to length of side of the writing surface is approximately 1 : 300 or, in the case of a quadratic writing surface, the ratio of spot area to writing surface area is 1 : 10^5. In the case of the precision oscillograph the ratio of spot diameter to length of side of the approximately quadratic writing surface is 1 : 30 000, and the ratio of spot diameter to writing surface area is 1 : 10^9 (10^9 image points).

For a distance of 200 mm between the deflecting system and the photographic plate, and an accelerating potential of 30 kV, a spot roughly 3 μ in diameter is obtained by means of a magnetic lens with small aperture to keep the deflexion error small. This lens stage is preceded by a stage using a magnetic pole-piece lens to demagnify the crossover of a directionally-controlled electron beam in the ratio 1 : The spot is focused by observing a grainless fluorescent mic screen (resolving power 3 μ) through a simple optical mic scope. The sensitivity of the deflexion referred to the s diameter, in the case of electrostatic deflexion, is 15–20 sp diameter per volt compared with 0·6–1 spot diameter per vo

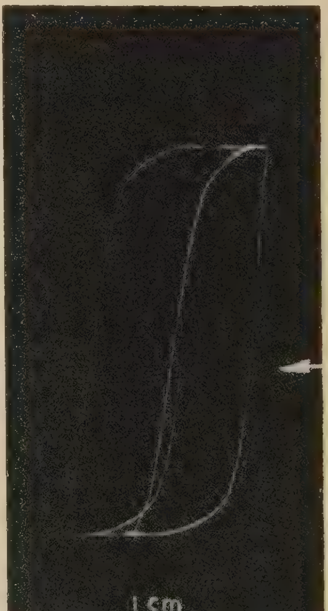

Fig. 1. Unmagnified reproduction of a hysteresis loop of kovar wire (1 mm diameter × 10 mm long), "written" with precision oscillograph at 50 c/s. A small additional deflexion throw in direction of the abscissa (see arrow) was applied towards the middle of the exposure time

ne case of a "Dumont 248" type standard oscillograph. ce it is very high, which for many applications ers the use of measuring amplifiers unnecessary. The llograph reveals the fine structure of oscillograms and acteristics. The two oscillograms reproduced in Figs. 1 2 will give an idea of the progress made, Fig. 1 shows normal reproduction of a hysteresis curve of 1 mm kovar "written" at a frequency of 50 c/s and a small additional exion-throw in the x-direction. The hysteresis curve in figure appears smooth, whilst the highly magnified on shown in Fig. 2 reveals the steps corresponding to the chausen jumps. In the (I)-marked cases we find a chausen jump at the same magnetization value.

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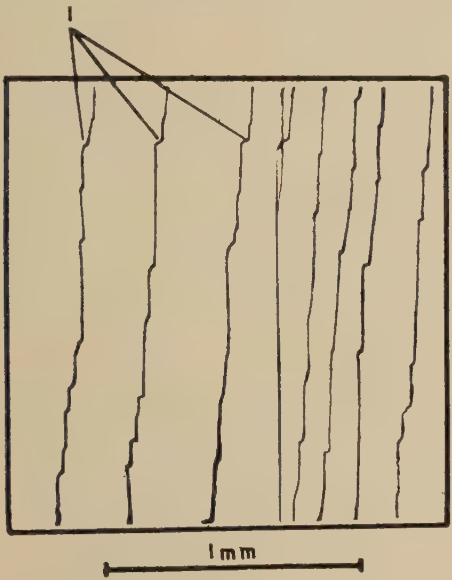
* von Ardenne, M. *Tabellen der Elektronenphysik, Ionenphysik und Übermikroskopie*, Vol. 1, p. 239 (Berlin: VEB Deutscher Verlag der Wissenschaften, 1956); *Nachrichtentechnik*, **5**, p. 481 (1955).

† von Ardenne, M. *Hochfrequenztechnik und Elektroakustik*, **54**, p. 181 (1939).

the case of plasma-physical investigations it was possible, the aid of this oscillograph, to observe the fine structures Langmuir's probe characteristic, characterizing the ility of the plasma. The instrument, which is on the to be manufactured industrially in the VEB Vakutronik sden A21, was also employed successfully for statistical stigations. Its range of application extends almost to



ig. 2. Part of hysteresis loop reproduced in Fig. 1, ighly magnified, showing the steps corresponding to the Barkhausen jumps

whole field of oscillographic measuring techniques, and to problems concerned with the testing of large transners, and with electro-medical research (such as the fine cture of cardiograms, nerve-action currents, fine structure lectrical brain currents, etc.).

A miniature dry-box for semi-conductor work

y P. R. Rowland, M.Sc., Ph.D., and G. W. Whiting, esearch Laboratories, The General Electric Co. Ltd., Wembley, Middlesex

[*Note received* 4 *September*, 1956]

well known that semi-conductor devices are sensitive to ace impurities, particularly to adsorbed water, and it is efore necessary to probe them or otherwise to manipulate n in a dry-box in order to investigate their electrical racteristics. This is usually carried out by operating a romanipulator in a large dry-box by means of rubber es sealed into the sides of the enclosure. In our experience it is more convenient instead to have the micromanipulator outside a small dry-box mounted on the stage of the manipulator itself. This arrangement, which involves the use of no large gaskets or rubber gloves, results in more certain conditions of humidity and gas purity than with the conventional dry-box. Because of its small volume the apparatus can be swept out rapidly and used for studying the effect of changes of gaseous ambient, direct comparison of characteristics over a short time interval being possible. Without the encumbrance of air-locks, rubber gloves, etc. manipulation can be carried out rapidly and with ease.

The micromanipulator probe extends into the dry-box through a suitable seal which allows movement in three mutually perpendicular directions (see figure). The box A is of glass. It carries a short side tube with a ground glass end on which slides a metal plate D, giving movement in two horizontal dimensions. To allow for any misalinements this is a loose fit on the probe stem P, but the weight W is a fairly accurate fit and the gap between the two is sealed by the neoprene washer G. The probe is held to the manipulator head M by the screw K. A suitably dried atmosphere is introduced at J. T is a specimen table of bent metal sheet with a handle E of metal rod fitting loosely in a bung C. B is a baffle, attached to the table, with a slit in it to direct a jet of drying gas parallel to the table-top. If required, the apparatus can be wound with resistance tape and experiments carried out at elevated temperatures. Suitable adaptions and modifications will suggest themselves for optical work, etc.

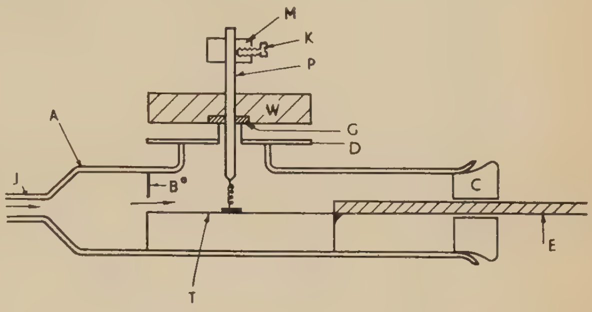


Diagram of miniature dry-box

An automatic constant level device for liquid nitrogen

By D. E. Henshaw, B.Sc., University of Western Australia, Nedlands, Western Australia

[*Note received* 3 *September*, 1956]

In designing a cryostat for X-ray diffraction work, it was found necessary to construct a device capable of maintaining the level of liquid nitrogen in a Dewar vessel to within one or two centimetres. The device described here appears to be simpler than those in the literature$^{(1-8)}$ and does have one advantage (V_1 and K_2 described hereunder) that could be incorporated in most such instruments (Fig. 1).

The activating element is a float which operates a mercury switch (K_1). Although this system has always been reliable it seems probable that a bimetallic thermo-regulator as used by Lounsbury$^{(6)}$ would be more satisfactory in many cases. The fall of the level of liquid nitrogen in the Dewar vessel allows the float to fall and close the mercury switch. Then, subject to K_2 (Fig. 2) being closed, a current flows through (*a*) a solenoid which closes the valve V_2, and (*b*) a heater in the reservoir flask which increases the pressure and causes liquid nitrogen to flow into the Dewar vessel.

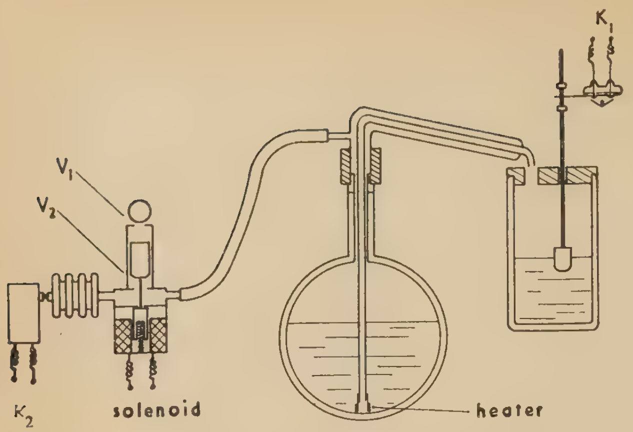


Fig. 1. Diagrammatic outline of constant level device

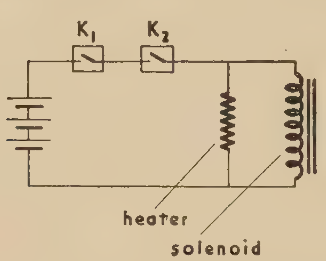


Fig. 2. Circuit of constant level device

The liquid nitrogen in the reservoir flask continually evolves gas by natural boiling and this gas maintains sufficient pressure to overcome the action of the valve V_1. This constant small pressure keeps the microswitch K_2 closed by means of a metal sylphon bellows. When the reservoir flask becomes empty this pressure is released through the delivery tube, opening K_2, and the device ceases to operate. The heater is wound on an open former attached to, but below, the end of the delivery tube so that it is always immersed in the liquid nitrogen when in operation.

The valves V_1 and V_2 operate under their own weight and the operating pressures can be changed by altering their masses. When not operating, the spring-loaded plunger of the solenoid keeps V_2 open. When the solenoid is energized, the plunger falls and V_2 is closed. The valve V_1 is simply a ball bearing resting in a hole of suitable diameter. Owing to the nitrogen vapour escaping from the reservoir flask, the ball bearing rattles and the "rate of rattle" is quite a useful indicator of the amount of liquid nitrogen in the flask. The microswitch could be arranged to activate an alarm when the reservoir flask is empty. Another modification which would be wise if liquid oxygen were used, would be to replace the heater with a source of dry, pressurized gas.

Over a long period of time the system has been reliable and has only required very occasional adjustment of the position of the microswitch.

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A simple instrument for the calibration of microscope fine-focus scales

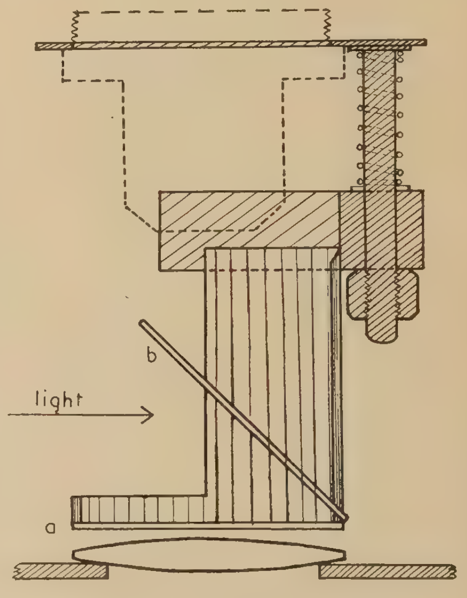
By J. B. A. England, B.Sc., Department of Physics, Queen's University, Belfast

[*Note received* 19 *September*, 1956]

Work with nuclear research emulsions sometimes requires accurate measurements in three dimensions.* In such work the vertical measurements are made on the fine-focus scale of the observing microscope, which must therefore be accurately calibrated. For this purpose a system has been used in which interference takes place between a plane glass disk attached to the microscope objective, and a long focus lens on the stage. The microscope itself is used to observe the Newton's rings formed. This method has the advantage over that of Barnard,† in that the microscope is calibrated under conditions similar to those in which it will be used.

An elevation of the instrument is shown in the figure. The glass disk *a* and the glass plate *b*, set at 45° to supply illumination, are held by means of three adjustable screws enclosed by helical springs below a low-power objective, on a frame through which the objective is screwed. The lower surface of the disk is at the focus of the objective. The instrument, combined with the low-power objective, has a total weight which is roughly equal to that of the high-power objective under which actual experimental measurements are made.

With a well collimated beam of monochromatic light, rings are easily observable when the plate and lens are separated



Section of calibration instrument with objective shown dotted distances up to 100 μ. The calibration is made by counting gs which move past a cross-wire for each nominal 10 μ the scale. One revolution of the fine focus control is also cked over 2 μ intervals.

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* See, for example, Duke, P. J., Lock, W. O., March, P. V., Gibson, W. M., McKeague, R., Hughes, I. S., and Muirhead, H. *Phil. Mag.*, **46**, p. 877 (1955).

† See, for example, Beck, C. *The Microscope.* Abridged ed., p. 194 (London: R. and J. Beck, Ltd., 1938).

rom measurements of this type are obtained the mean olute displacement corresponding to a scale division, the an deviation from this value at any part on the scale, the ition of any inaccurate or rough points and also a measure he random error of individual settings.

he errors found in some microscopes have been large ugh to demonstrate very clearly the need for the calition of any instrument which is to be used for the accurate asurement of vertical distances.

A thermistor probe

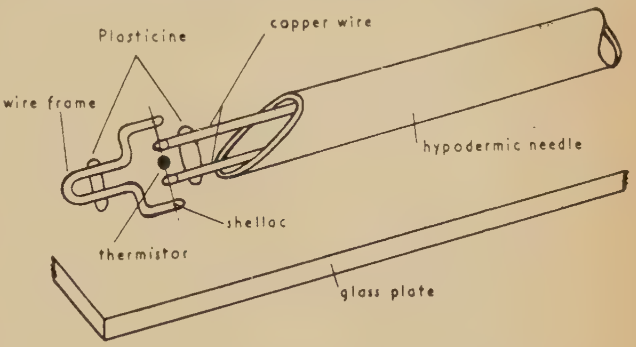
By W. Belfield, M.Sc., and R. W. Johnson, University College of the Gold Coast, Accra, West Africa

[*Note received* 15 *November*, 1955]

authors were concerned with the making of a fine probe ch would measure accurately to a tenth of a degree at temperatures (20–30° C). This was achieved eventually the use of a thermistor mounted inside a No. 1 hypodermic dle (diameter 0·8 mm). The thermistors used (type 361/20 by Standard Telephones and Cables Ltd.) showed satisfactory sensitivity in this low temperature range, 50 Ω/°C. The probe was then connected into a Wheatne bridge. The method of mounting is shown in the ire and described below.

wo 6 cm lengths of 40 s.w.g. enamelled copper wire were ightened and the ends cleaned and tinned with 40/60 alloy lticore solder for about $\frac{1}{2}$ mm. All traces of flux were noved and the wires inserted in a No. 1 hypodermic needle h the soldered tips projecting 1 cm from the needle tip, ich had been ground to a 20° point.

he thermistor was attached to a wire frame with shellac facilitate soldering. The assembly was performed on a glass plate with the components held in position with all pellets of Plasticine. The platinum-iridium/copper joints were made with a minimum of solder. The surplus thermistor leads were then trimmed to the joint and the Plasticine removed. Great care was necessary in performing this operation. The copper leads were then drawn into the hypodermic needle until the thermistor bead lay centrally on the needle tip. A small quantity of Ohmaline air-drying varnish (by Griffiths) was applied to the tip and allowed to dry for two days. The terminal ends of the copper lead wires were sealed to the hypodermic head by dropping a small quantity of the varnish into the head between the leads whilst the hypodermic was suspended in the vertical position, tip downwards. The probe was left in this position for forty-eight hours to allow the varnish to harden, and then tested for continuity and insulation resistance.



Method for soldering thermistor to copper wire

The above technique proved satisfactory, but it is thought that a more mechanically robust seal might result if a thermosetting resin, such as Araldite, were used.

This instrument has proved itself robust, accurate and ideal for both laboratory and field use. Preliminary tests have shown that by using two such thermistors in a Wheatstone bridge, it will be possible to measure very small differences in air movement, i.e. 1 in./s. The authors are also intending to attempt humidity measurement on a wet and dry bulb principle.

NOTES AND NEWS

Correspondence

proportional counter tube for X-ray diffraction analysis

would like to draw attention to certain errors in the thematical part of the paper by Mr. Skertchly, published p. 209 of the June 1956 issue of this *Journal*. He assumes t all photoelectrons are liberated perpendicular to the ay beam, but calculates θ in a plane perpendicular to the gitudinal axis of the counter. The section of the counter ntaining D and r is, of course, an ellipse of minor axis b d major axis $b \sec \psi$. In this case the value of θ is given the solution of the equation

$$\sin^2 \psi \cos^2 \theta + 2r \cos \psi \cos \theta (D \cos \psi - b) - D^2 \cos^2 \psi + 2bD \cos \psi - r^2 = 0.$$

s shown below, for $\tan \psi = 0{\cdot}1763$ this expression gives imilar result to that obtained with Skertchly's approximate ression, but the fact that it is an approximation is liable be overlooked unless some mention is made.

In the calculation of the total fraction of photoelectrons liberated within wall range, it seems unreasonable to discard the term θ/π. This varies from approximately 0·5 to 0 over the range of integration, whilst the remainder of the integrand stays nearly constant. The values given in the paper for the variables give arcos $(r/2b) \simeq 88°$, i.e. $\theta \simeq 92°$ [the expression arcos $(r/2b) \simeq 80°$ makes $b = 0{\cdot}1$ cm], and the total fraction of photoelectrons liberated within wall range is $A = 0{\cdot}046$, if the approximation for θ is used and the θ/π term is neglected. If θ/π is included, then $A = 0{\cdot}015$. If the correct expression for θ is used and the θ/π term is included then $A = 0{\cdot}015$.

The approximation of θ does not therefore alter the value of A, but neglecting the θ/π term from the integrand alters the result by a factor of 3.

Atomic Weapons Research
Establishment,
Aldermaston, Berks.

F. H. Sumner
D. P. D. Webb

[5 November, 1956]

The mathematical section of the note referred to was intended to be indicative only of the magnitude of the "wall effect" since the problem did not appear to justify an exact solution. My expression for θ should have been preceded by "as ψ is small" and then $\theta \simeq$, etc., although this limitation is implied in the text.

Should an exact analysis be required then the refinement of Sumner and Webb should be incorporated and the assumptions (i) and (ii) replaced by appropriate distribution functions.

In the process of obtaining a high estimate the θ/π term is not neglected, but the value of θ at $x = 0$ should be approximately 90° as is indicated by the successive approximation in the next line.

May I also add that counters with similar characteristics may be constructed using carbon dioxide to replace the ethyl alcohol as quenching agent, and that the operating potential is normally around 1650 V.

In Fig. 1 the window thickness should be $\simeq 0{\cdot}02$ mm.

Textile Physics Research
Laboratory,
The University of Leeds.

A. R. B. SKERTCHLY
[26 November, 1956]

A Fourier analogue-computer of the Hägg–Laurent type

Since the original description by Hägg and Laurent* of an electromechanical computer for Fourier synthesis and analysis, several machines of this particular type have been constructed and have been working for a number of years. In spite of the development of digital computers there still seems to be a need for moderately sized and relatively inexpensive analogue computers, especially for crystallographic work.

This letter describes some modifications incorporated in a recently constructed machine of the Hägg–Laurent type. The general principles are given in the original paper by Hägg and Laurent.

The machine is able to handle twenty sine and twenty cosine terms, giving the sum value at intervals of 6° in the range 0–360°. The main differences from the earlier types are the following.

(*a*) The coupling aggregate which produces all the harmonics (of one sign only) are here made up of seven uniselectors (L. M. Ericsson, type R.V.F. 12). These are of a six-pole, thirty-step type and will thus generate the harmonics only in the range 0–180°. Noting that the even harmonics repeat in the range 180–360°, whereas the odd harmonics repeat with a change of sign, this difficulty is overcome in the following way: the positive and negative busbars from the sign selectors for all odd harmonics pass through the contacts of the relay R_1 (Fig. 1) before going to the summation transformer T_1; the sign of the odd harmonics are thus reversed when R_1 is actuated, which is done by a "scale of two" mechanism (actually a relay of special construction); this in turn is triggered by means of a contact on the uniselectors every time these pass through zero position. In this way all harmonics are correctly generated for every two full turns of the uniselectors. To ensure small contact resistances, the a.c. signals through the uniselector-contacts are superposed with direct currents of greater amplitude (circuits not shown on Fig. 1).

We may notice the following advantages in using commercially available switching components:

(i) the mechanical work necessary in the construction is reduced;

(ii) the stepping of the machine from one x-value to the next one is quickly performed electrically; means for manual as well as for automatic stepping have been provided;

(iii) the risk of short circuiting in the uniselectors is very small and no elaborate protecting system has proved necessary.

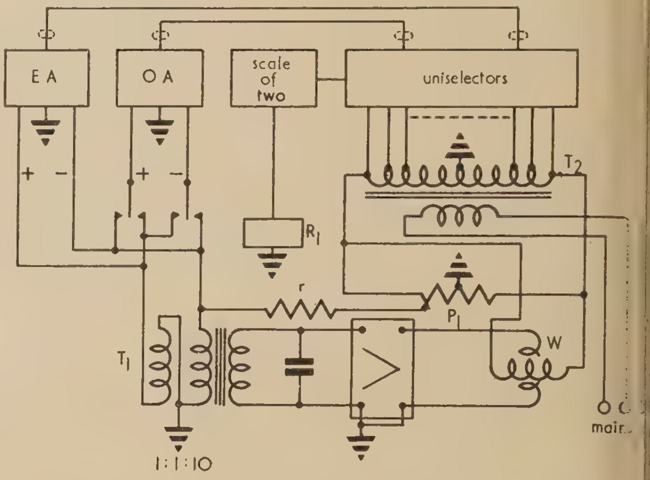


Fig. 1. Functional diagram of Fourier computer

EA contains the amplitude and sign selectors for all even harmonics, *OA* those for all odd harmonics. T_2 is wound on a 1 kW core (secondary voltage 2 × 20 V) in order to produce fixed terminal voltages independent of loads. Other parts described in the text.

(*b*) The amplitude selectors are carried out as two-decade units (Fig. 2). Resistors r_1 are wire wound with a tolerance of 1%, but sorted in banks of ten with a relative accuracy of 2 parts per thousand in each bank; r_2 is also wire wound

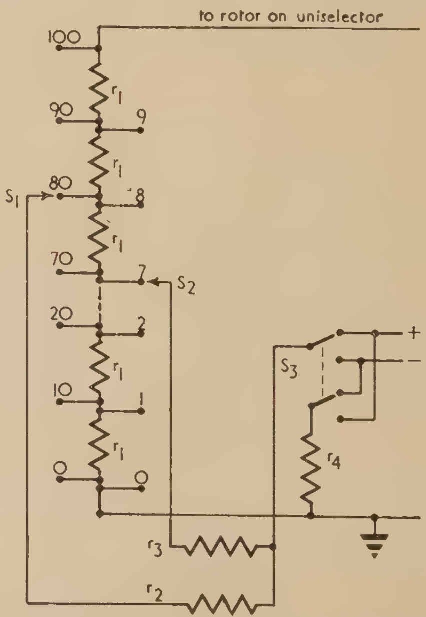


Fig. 2. Circuit of an amplitude and sign selector unit

$r_1 = 100\ \Omega$, w.w.; $r_2 = 100\ \text{k}\Omega$, w.w.; $r_3 = 1\ \text{M}\Omega$ (carbon); and $r_4 = 91\ \text{k}\Omega$ (5% carbon).

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* HÄGG, G., and LAURENT, T. *J. Sci. Instrum.*, **23**, p. 155 (1946).

lerance 1 part per thousand), whereas r_3 is a 5% crystal-
carbon resistor. The decade switches S_1 and S_2 are of
ood quality radio type; S_3 is a sign switch. It is thought
t this arrangement will give a better accuracy and longer
e stability than potentiometers of normal radio type; the
ting of the selectors also seems easier. The resistor r_4
ves to keep the impedance level of the positive and
ative busbars fixed, independent of the position of the
switches.

c) As the uniselectors generate harmonics of one sign only
paragraph (*a*)] two output terminals from the amplitude
sign units are necessary. The circuit by which the sign
sitive summation of the currents from all these units is
formed and the compensating circuit for measuring this
n value are indicated on Fig. 1: the resulting currents
m the positive and negative busbars are sent through the
osite halves of the primary of the transformer T_1, which
of the differential type (the primary is wound with two
es in parallel); in addition current from the precision
entiometer P_1 is impressed (through the resistance r) on
-half of the primary of T_1. If this current does not equal
difference between the currents from the positive and
ative busbars respectively, the resulting ampere-turns
s present will cause an induced e.m.f. in the secondary
ding of T_1; this winding is resonated to the measuring
quency (50 c/s), and the signal, after amplification, excites
of the coils of the wattmeter W, acting as a phase-sensitive
o-indicator. By setting P_1 so that W shows zero deflexion,
desired sum value may be read on the calibrated scale
P_1. To facilitate this procedure the pointer of W has been
anged to move just behind the scale of P_1.

The machine has been in use for six months without much
uble; the accuracy is such that deviations from the real
n value very seldom exceed 1 to 2 units on the lower
asuring range (−200/+200 units), and 3 to 5 units on
higher range (−2000/+2000 units). As illustration we
y quote the results for the example given by Hägg and
urent; deviations from 0 to 1 (numerically) occurred
enty-four times, from 1 to 2 occurred six times and no
viations higher than 2 were observed. (N.B.—The real
ue was recalculated by means of tables to a higher accuracy
n that given by Hägg and Laurent.)

Machine calculation of a sixty-point one-dimensional series
h forty-one terms may be performed in 10–15 min.
perience shows that the time spent on actual crystallo-
phic problems is one-fifth to one-tenth of the time
essary for calculations of the same problems by strip-
thods. It should also be noted that in summations involv-
3° intervals the even harmonics may be summed on the
chine, leaving only the odd harmonics to be summed by
ips.

This work was made possible through a grant from The Danish State Research Foundation to Prof. A. Tovborg Jensen. The mechanical work and the wiring was skilfully performed by Mr. K. Bøgemose. The writer is pleased to acknowledge the valuable suggestions concerning this type of computer received from Profs. G. Hägg and T. Laurent and Techn. Lic. S. V. Berger.

Physics Department,
Technical University of Denmark,
Copenhagen,
Denmark.

V. Frank
[29 October, 1956]

Comments on the A.S.T.M. Powder Data File

In February 1956 the writers published a list of errors in and comments on the X-ray Powder Data File.(1) This list was described briefly in the Institute's journals.(2) As a result of this publication, and of the appearance of a sixth set of data cards which was issued in 1956, a number of further errors have come to light and further comments have been sent to us. These have been collected in a booklet having the same title as that above, and copies have been sent to (i) all members of the X-ray Analysis Group of the Institute of Physics, (ii) all who have purchased copies of the Data File through the Institute, and (iii) all who have obtained copies of the first booklet from the writers. Others who would like to have copies of the booklets may obtain them on request from the Institute or from us.

The Committee of the X-ray Analysis Group of the Institute of Physics has authorized the publication of such lists of comments at approximately annual intervals. Users of the Data File are urged to send to the writers any material that they feel should be included in future "Comments."

Viriamu Jones Laboratory,
University College, Cardiff,
S. Wales.

J. W. Hughes
Isabel E. Lewis
A. J. C. Wilson

REFERENCES

(1) Errors in the A.S.T.M. Index of X-ray Powder Diffraction Patterns. Cardiff: Viriamu Jones Laboratory. Pp. 39 (1956). [In June 1956 the Joint Committee on X-ray Diffraction Methods agreed that the name of the card file be "X-ray Powder Data File," and that the book index be called "Index to the X-ray Powder Data File." The title of the second booklet has, therefore, been altered correspondingly.]

(2) Hughes, J. W., Lewis, I. E., and Wilson, A. J. C. *Brit. J. Appl. Phys.*, **7**, p. 80 (1956). *J. Sci. Instrum.*, **33**, p. 86 (1956).

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved products. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

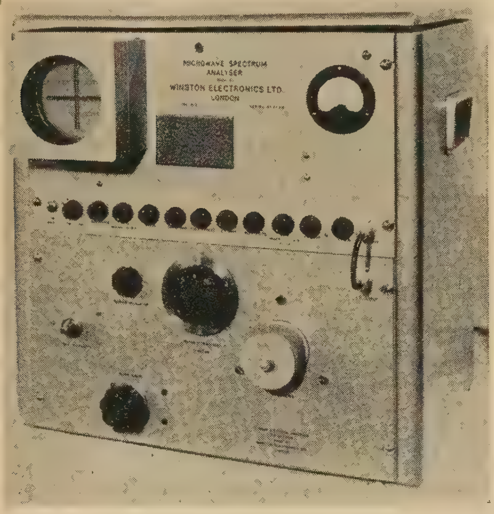
Spectrum analyser for the S, X and L bands. Winston Electronics Ltd., Shepperton, Middlesex.

This spectrum analyser is a universal instrument for the precision measurement of the spectra of pulsed signals in the *S*, *X* and *L* bands and it may be used as a sensitive receiver of the frequencies covered by these bands.

The requisite spectra are displayed on a 5 in. long persistence cathode-ray tube. The pictures are steady and bright and the bezel of the cathode-ray tube has been designed to enable recordings to be made with the Cossor Model 1428 oscillograph camera.

The equipment consists of an electronic rack and of interchangeable R.F. sections. Both racks are fitted into a single case. The simple interchange of R.F. sections permits operation at any of the three bands specified. In cases where operation at *X*-bands only is required the waveguide components may be mounted on the panel of the electronic unit. In such a case the overall height of the instrument is halved.

The analyser is designed for the viewing of signals of pulsed length ranging between 0·2–2·5 μs at repetition frequencies from 200 to 3000 pulses per second.



Spectrum analyser for the *S*, *X* and *L* bands

A klystron forms the local oscillator and this can be electronically frequency modulated over a range which depends on the frequency band. Tuning is done mechanically and a rough indication of frequency is provided.

The input signal, suitably attenuated, is mixed with the output of the klystron oscillator, the resulting heterodyne output from the crystal mixer, which is frequency-modulated at the same rate as the local oscillator, is applied *via* a 70 Ω cable to a 20 Mc/s intermediate frequency amplifier, which has a bandwidth of 50 kc/s. The output from the intermediate frequency amplifier is mixed with a differentiated video signal from the crystal mixer, further amplified, and applied in push-pull to the *Y*-plates of the cathode-ray tube.

Since the deflecting voltage applied to the *X*-plates is also used to frequency-modulate the klystron, the horizontal deflexion is proportional to frequency, while the vertical deflection is proportional to the power spectrum.

Determination of the spectrum width and the centre frequency is obtained by means of a wavemeter pip and/or pip marker oscillator. The latter is fitted only to *S* and *L* band analysers and provides crystal controlled pips at 1 Mc/s intervals.

The signal from the transitron part of the Miller time base mixed with a video signal present at the *Y*-plate is applied to the grid of the cathode-ray tube, providing both blanking of the flyback trace and intensifying the brilliance of the spectrum.

Facilities for checking the operation of the local oscillator are provided: the local oscillator current can be displayed on a meter and the klystron modes can be displayed on the cathode-ray tube.

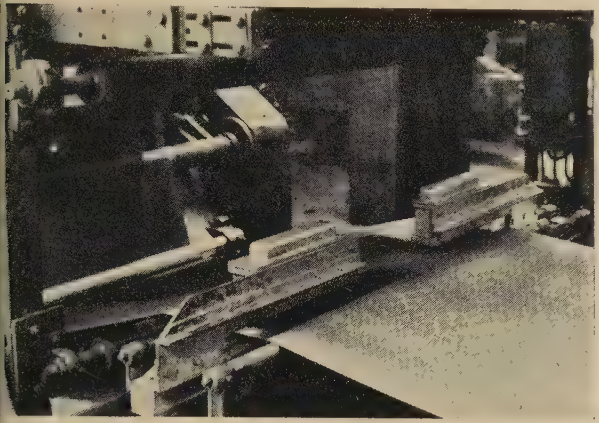
The type of wavemeter fitted depends on the frequency band. At *X* and *S* a cylindrical cavity resonator operating in the TE_{011} mode is employed. The *Q*-factor of this type of wavemeter is approximately 15 000. At *L*-band a hybrid type of cavity is employed. At the high frequency end of the band the mode of operation is the cylindrical TM_{010}, whereas at the low frequency the capacity-loaded coaxial line resonator is used. The transition between the two modes is quite smooth. The average *Q* is 4000.

The accuracy of absolute frequency measurements is given by the makers as $\pm 1 \times 10^{-4}$ of the frequency. Relative frequency measurement may be made to within ¼ Mc/s.

Beta-ray thickness gauge. Isotope Developments Ltd., Beenham Grange, Aldermaston, Berks.

Gauges based on the absorption of β-rays are now being extensively employed in the manufacture of sheet materials for measurement of the thickness, or weight, of the sheet. The principle of the method is that the source of β-radiation is mounted on one side of the material to be inspected and an ionization chamber on the opposite side. The current through the chamber then depends on the attenuation produced by the sheet. Several types of source are available, so that it is possible to choose one for which there is a large difference of attenuation for a small difference in thickness of the sheet being inspected. It is thus possible to make accurate measurements over a range of materials from a few g/m^2 up to 12 kg/m^2. The range of weights of the materials manufactured on one machine is often such that it is not satisfactory to indicate weight directly on a meter: small variations from any set weight would be difficult to distinguish. For this reason, beta gauges are usually provided with one control which will set the desired weight and an "off gauge" meter which shows variations from the selected weight. This system allows an operator to distinguish easily variations of ±1% in the material being measured. The usual way of achieving such a centre zero indication is to provide a second source and ionization chamber and to measure the difference of the two outputs. When measuring material of the correct pre-determined weight, the zero reading will be independent of drift in the electronic circuits, decay of the sources and variations of temperature and humidity of the air. Using conventional chambers, it is necessary to ve access to the measuring unit to make adjustments when nging the weight of material being measured. In the new pe 150 gauge, this disadvantage is overcome by fitting the ancing chamber with a grid electrode. This makes it ssible to control the output of the chamber by a potentio-ter at the control desk.

The normal measuring area of this gauge is 12 × 2 in. and es an average reading over a large sample of material for ocess control. This area can be reduced to 6 × ½ in. for estigations of local variations in the sheet. The response ne is variable from 0·1 to 10 s, so that short-term variations n either be ignored, as in normal process control, or orded during special investigations. The "off gauge" ter can be sited remote from the gauge, and has a scale gth of 16 in. Meter indications of ±1% are easily read a distance of 10 yd. A small setting-up meter is provided the control unit which carries the weight setting dial. is control is calibrated to suit individual requirements after gauge is installed. The sensitivity of the "off gauge" ter to variations in weight is variable to a maximum of 5% for full-scale deflexion. Recorders are available to e permanent records of gauge readings, and the output the gauge may be used to actuate controllers to govern chine speed, etc.



Beta-ray thickness gauges attached to machine producing sheet rubber fabric

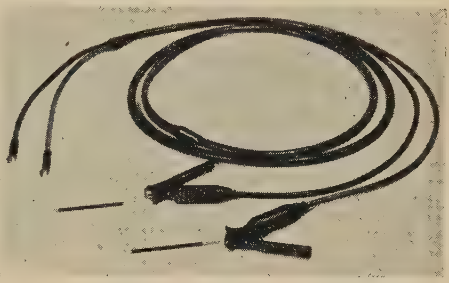
nsistor-operated portable scaling unit. Dynatron Radio Ltd., The Firs, Castle Hill, Maidenhead.

e Type 1287A portable five decade scaler is designed for luous use where the essential requirements are compactness l independence of mains supply. The scaler provides a arizing voltage in the range 350–435 V, suitable for the ogen-quenched type of Geiger tube. Pulses from the tube fed to a five decade scaling circuit of adequate sensitivity l resolving time for Geiger counting. This circuit com-ses five cold cathode Dekatron tubes driven by germanium ction transistors, enabling a total of 99 999 counts to be istered. A robust built-in stop-watch provides automatic ing, and two methods of counting can be used. In the t, the stop-watch is started in synchronism with the start the scaling unit and is stopped electronically when the end a pre-selected total count of 10^2, 10^3, 10^4 or 10^5 is reached. the second method, the stop-watch is started in syn-onism as before and is manually stopped to stop the ling unit counting.

Transistor-operated scaling unit and battery carrying case

Fused connecting leads. Ferranti Ltd., Hollinwood, Lancashire.

These general-purpose test leads consist of a 6 ft length of tough rubber sheathed flexible cable insulated for 660 V. One end is terminated by a spade terminal and the other by a strong crocodile clip having stainless steel jaws and insulating handles. A 5 A cartridge fuse is fitted in the handle and a moulded synthetic rubber sheath covers all but the ends of the clips. Insulated test prods are provided for insertion in the clips when required.



General purpose connecting leads

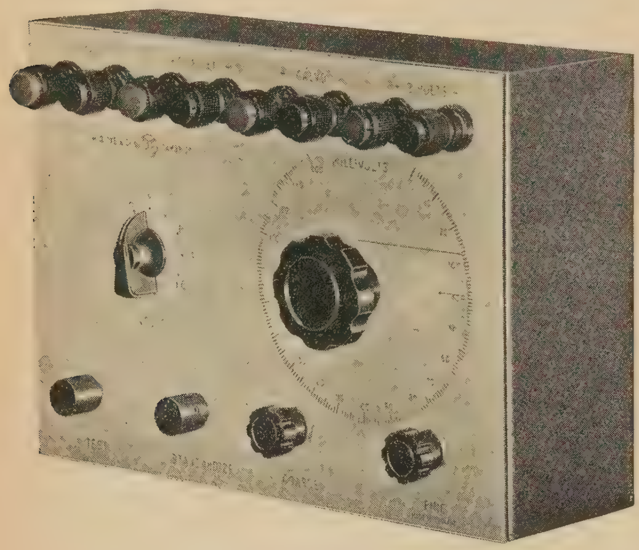
Nuclear reactor computers and simulators. Elliott Brothers (London) Ltd., Century Works, Lewisham, S.E.13.

Analogue computing techniques have been developed for the simulation of the many mathematical relations involved in the design of a nuclear reactor. The largest of the computers, type ND 111, consists of seven cabinets. One of these simulates the reactor kinetics equations, and pre-set controls enable coefficients to be set according to the fissile material chosen. Step changes in reactivity can be inserted as well as changes proportional to various factors such as temperature, poisoning, etc. The unit is wired for six reactor kinetics equations with five groups of delayed neutrons. Delay constants and delayed neutron fractions are set in by manual controls. The remaining six cabinets are for simulation of the remainder of the power station, e.g. heat exchangers, turbines, alternators, etc. There are enough amplifier units to permit representation of a large number of simultaneous equations. Multiplication is performed by high-speed servo-multipliers operating from the standard amplifier units. A transit time-lag simulator permits the inclusion of the effect of coolant transport from reactor to heat exchanger; this time lag is continuously variable and can be controlled from the voltage output from an amplifier unit. The computer is arranged so that two independent problems may be solved at the same time.

A smaller computer, type ND 115, is constructed as a desk unit and is intended for design studies of the reactor only. A reactor simulator, type ND 181, is intended for use in training reactor operators or for teaching in technical colleges and universities. It is built to represent a typical reactor console and serves to demonstrate the effect of the various controls and to provide a rapid appreciation of operating technique.

General-purpose potentiometer. W. G. Pye and Co. Ltd., "Granta" Works, Newmarket Road, Cambridge.

The type S potentiometer, illustrated below, is intended as a low-priced instrument for use in educational and research laboratories where the highest accuracy is not required. The instrument covers the range 0–1·8 V with an accuracy of 0·1% or ½ mV. The operating panel carries the main dial switch covering 0–1·6 V in steps of 0·2 V, and a circular slide-wire reading to 200 mV calibrated at intervals of 1 mV. The coarse and fine rheostats for current control and the test and standardizing keys are situated at the lower edge of the panel. A useful feature for educational purposes is that the circuit diagram is displayed on the underside of the case which is kept clear of the bench by four small metal feet.



General purpose potentiometer

Low frequency attenuator. Advance Components Ltd., Roebuck Road, Hainault, Essex.

The type A64 attenuator has a constant input and output impedance of 600 Ω. It covers the range 0–70 dB with two control knobs: one giving six steps of 10 dB and the other ten steps of 1 dB. The unit is designed essentially for use with audio-frequency apparatus and is stated to have negligible error at frequencies below 200 kc/s and an error of less than 2·5 dB at 1 Mc/s, An accuracy of adjustment of 1% is claimed.

Direct reading magnetometer. Newport Instruments Ltd., Newport Pagnell, Bucks.

The magnetometer is designed to measure fields up to 500 oersted in three ranges. The principle of operation is the gyromagnetic coupling in a ferrite. A ferrite toroid is excited to saturation by a toroidal winding, and a solenoid is wound on the core at right angles to this winding. In the presence of an external magnetic field, a voltage appears across the solenoid proportional to the value of the field and at a frequency of twice the exciting frequency. The output from the solenoid is fed into a stabilized-gain, tuned amplifier, the output of which is measured by a valve voltmeter. The indicator is a 4 in. circular scale meter on the front of the instrument. An electrical output is also provided so that slowly varying fields may be displayed on an oscilloscope or pen recorder. Owing to the temperature coefficient of $B(sat)$ for ferrites, a thermometer is to be provided in the probe unit so that an accuracy of better than 2% is obtained when the appropriate temperature correction is applied. Since the short term accuracy of the instrument is better than 1%, a standard calibrating solenoid is available to enable the absolute value of a field to be determined to this accuracy.

Piezoelectric ceramics. Technical Ceramics Ltd., Wood Burcote Way, Towcester, Northamptonshire.

Information has recently been published of an extensive range of piezoelectric units composed of a barium titanate ceramic electrically polarized so as to have many of the characteristics of a single crystal. These ceramics are available in standard sizes as cylinders or disks, and as rings or tubes. The first type are made in diameters from 10 to 75 mm and in thicknesses from 0·25 to 25 mm, the natural frequencies for thickness vibrations ranging from 10·4 Mc/s to 104 kc/s. Such units are supplied to a tolerance of 10% in frequency. Rings or tubes are available in lengths from 1 to 6 in. and diameters from 1 to 4½ in., the wall thickness being usually ⅛ in., corresponding to a radial vibration frequency of 820 kc/s. The ceramics are supplied with silver coatings to act as electrodes. They are employed in ultrasonic generators, strain gauges, accelerometers and as components in electric filters and oscillators.

Microwave wattmeter. E.M.I. Electronics Ltd., Hayes, Middlesex.

The Type 1 wattmeter exploits certain novel features of the well-known phase-shift oscillator which has a thermistor in the feed-back bridge to keep the amplitude of the oscillation constant. The ordinary thermistor is replaced by an r.f. thermistor, which is used as the termination of the r.f. power to be measured. Owing to the fact that the thermistor is kept at constant resistance and temperature by the self-adjusting features of the oscillator circuit, the termination impedance is independent of the power level being monitored. Thus the change in oscillator current flowing in the thermistor is a direct measure of the change in r.f. power. The resistance arm of the bridge is made adjustable, so that the level of oscillation can be adjusted to give different thermistor impedances. The instrument covers the power range 0–4 mW in steps of 100 μW with an accuracy of 4%. It can be used with a directive feed to measure greater power. The voltage standing wave ratio created by the termination is stated to be about 0·95 under ideal conditions.

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

Strain gauges. Baldwin-Lima-Hamilton, Electronic and istrumentation Division, 43 Fourth Avenue, Waltham 54, lass., U.S.A. A 14-page bulletin lists several gauges of terest. The constantan wire fine pitch rosette flat grid, id the temperature compensated grids for use on titanium id quartz are offered for the first time.

Measuring instruments. Brüel & Kjær, Naerum, Denmark. 26-page illustrated catalogue lists a wide range of instru- ents for electrical and acoustical measurements, vibration ialysis, electro-chemical measurements and measurement of dioactivity.

Immersion heaters. The Thermal Syndicate, P.O. Box No. 5, allsend, Northumberland. A 7-page booklet describes itreosil electric immersion heaters, having PVC caps, which n be used for all acids including chromic acid.

Metallurgical instruments. Nash and Thompson Ltd., akcraft Road, Chessington, Surrey. An 8-page illustrated aflet includes details of an electrolytic polisher for metallo- aphic specimens. This apparatus can be used for processes her than for electrolytic polishing where a d.c. potential is quired.

Digital computer. Metropolitan-Vickers Electrical Co. td., Trafford Park, Manchester 17. A 13-page illustrated ooklet describes a new electronic digital computer which a general purpose model capable of application to a wide iriety of mathematical problems in research and engineering esign. The new unit is called the Metrovick 950.

Analogue computer. Short Brothers and Harland Ltd., ueen's Island, Belfast. A general purpose analogue com- iter is described in a 9-page illustrated brochure. The omputer will provide a graphical solution to a particular oblem that has been established, either in the form of a ace on a cathode-ray tube or a graph on a paper chart.

Scientific and Technical publications. Hilger and Watts Ltd., 3 St. Pancras Way, Camden Way, London, N.W.1. A italogue (CH125/22) lists publications available from this rm on the following subjects: absorption spectrophotometry, -rays and crystal structure, spectrochemical analysis and ectroscopy, tables and maps of spectra and general books.

Compressed-air-operated controllers, transmitters and re- orders. Negretti and Zambra Ltd., 102 Regent Street, W.1. ublication R35/1 describes a new design of compound ontroller. Publication R36 describes a time/temperature ecorder/controller for industrial processes; an illustrated velve-page brochure describes air-operated, force-balance pe temperature transmitters.

Servo-mechanisms. Ketay Ltd., Eddes House, Eastern venue West, Romford, Essex. A brochure describes a ew range of high accuracy miniature servo-mechanisms. ull performance figures of Ketay synchros are quoted and istallation diagrams are included.

Ovens and incubators. Emil Greiner Co., 20–26 North lorre Street, New York 13. Bulletin No. 376/C describes art of the range of ovens and incubators, designed for boratory use.

Optical units and benches. R. and J. Beck, Ltd., 69/71 lortimer Street, W.1. A 16-page illustrated catalogue gives i indication of the extensive selection of optical units and enches which this firm produces.

Strain gauges, instruments and accessories. Baldwin-Lima-Hamilton, 42 Fourth Avenue, Waltham 54, Mass., U.S.A. A 16-page catalogue gives latest details of the prices of the instruments and accessories which are manufactured by this firm.

Summation metering. Ferranti Ltd., Hollinwood, Lancs. Brochure 1S.6 describes various methods of summation in general use and contains details, with illustrations, of wide range of summation metering equipment supplied by the Company.

Freeze-drying equipment. Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex. Booklet No. E. 203/1 and Leaflet No. E 183/3 describe a range of freeze-driers from the small L5 unit for research work to the large model 51 production machines.

Photometers and densitometers. Baldwin Instrument Co., Ltd., Dartford, Kent. Leaflet 117/2 describes a range of photometers and densitometers and in particular the comparator densitometer which is a new instrument.

Electronic instruments. Airmec Ltd., High Wycombe, Bucks. This company has made available a folder containing over 100 descriptive leaflets and technical bulletins giving full details of their standard range of electronic instruments.

Surface roughness scales. Rubert & Co., Ltd., Chapel Street, Levenshulme, Manchester 19. A leaflet describes an improved pocket size model (Set No. 24 MKII) of this firm's surface roughness scales.

Master slave manipulator. Savage and Parsons Ltd., Watford, Herts. Publication No. 7/5 gives details of the model SP8 master slave manipulator which makes possible the remote control of complex operations on radio-active or toxic materials.

Computer components. Electro-Mec Laboratory Inc., 47–51 33rd Street, Long Island City, N.Y. Four leaflets have been issued describing linear and non-linear potentiometers (Types 11, 18 and 1395) and a digitometer (Type 15B).

Packless steam solenoid valve. Automatic Switch Co., 391 Lakeside Avenue, Orange, N.J., U.S.A. Bulletin No. 8222A describes internally pilot operated solenoid valves which may be used in a variety of applications where the automatic control of the flow of steam, hot fluids or gases (up to 400° F) is essential.

Electronic and nucleonic equipment. General Radiological Ltd., 15–18 Clipstone Street, Gt. Portland Street, London, W.1. A series of leaflets describe the following instruments: Scaler unit (Type 1366 A); General purpose ratemeter (Type 1161 B); A combined beta and gamma ionization chamber for the maintenance of standards of radioactive nuclides (Type 1383 A); Geological survey unit (The Red Box). This instrument is intended for the detection and measurement of gamma radiation; E.H.T. power unit (No. 1359A). This instrument has been designed for use where a very stable source of high voltage free from ripple and pulses is required.

Tap changers. Claude Lyons Ltd., Valley Works, Ware Road, Hoddesdon Herts. A 6-page folder describes an automatic tap changing unit which automatically ensures input voltage to the instrument.

Microscopes. W. Ottoway & Co. Ltd., Ealing, London. Booklets describe the Orion low power stereoscopic microscopes, the Orion students microscope, and microscope lamps and fittings.

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

Fellows: E. Atherton, A. Barker, E. George, R. L. Gordon, H. A. Hughes, S. E. Hunt, P. L. Kirby, C. Mack, R. Parker, H. V. Pilling, V. Robert, H. W. B. Skinner, E. G. Stanford, S. Thornton, B. M. Wheatley.

Associates: C. Ambasankaran, D. Aston, A. C. Baker, W. A. D. Baker, R. A. Bembridge, N. F. Blackburne, W. E. Boud, J. D. H. Bradley, M. Bridger, J. Bunton, G. H. Byford, J. A. Champion, J. Chayen, C. A. Cochrane, W. E. Craker, H. M. Dean, J. A. Dennis, R. Diamond, E. Dyson, R. Elam, J. Ellis, W. G. Ferrier, L. Finkelstein, D. F. Fyfe, B. E. Godfrey, B. J. Gumm, A. M. Hardie, J. Houghton, T. P. Hughes, T. F. B. Jaggar, J. K. Jones, P. G. Lea, Y. K. Lim, J. Luff, D. E. Macdonald, R. C. McVickers, I. G. Matthews, A. D. Maude, F. R. Morgan, J. A. Morgan, J. Nightingale, F. J. Pearson, J. Potts, J. A. Reynolds, J. Richards, A. Rimmer, S. F. Robinson, J. B. Rowcroft, C. Rubenstein, C. M. H. Smith, L. N. Snell, G. M. Somerville, D. G. Strahle, A. W. Stirling, J. G. Tapley, A. R. Thomas, P. M. Tipple, P. W. Turner, J. Varma, S. M. Y. Wafaquani, J. Wardley, H. Whitehouse, P. W. Wright, B. Yates, K. W. Young.

Seventy-four Graduates, sixty-six Students and five Subscribers were also elected.

Bibliographies and reading lists from the Atomic Energy Authority

In accordance with the United Kingdom Atomic Energy Authority's policy of disseminating information on atomic energy, its technical information officers from time to time prepare bibliographies on selected subjects and a list of those already prepared is obtainable from its Chief Press Officer at St. Giles Court, St. Giles High Street, London, W.C.2, together with details saying from where they are obtainable.

Within the limits of available effort the Authority will prepare further bibliographies in answer to requests from industry, learned societies, universities, technical colleges and other research institutions. Priority will naturally be given to subjects for which there is most demand. Requests should be sent to the Librarian, A.E.R.E., Harwell, Berks, or the Chief Librarian, U.K.A.E.A. Industrial Group, Risley, Warrington, Lancs. There is close collaboration between the Groups, and inquiries will be forwarded to the appropriate Library for action.

Register of British manufacturers

The twenty-ninth edition (1957) of the F.B.I. register of British manufacturers classifies the products and services of over 7000 firms who are members of the Federation of British Industries. The headings used are: products and services, addresses, trade associations, brands and trade names, trade marks. In addition there are language glossaries in French, German and Spanish.

The register is published by Kelly's Directories Ltd., and Iliffe and Sons, Ltd., Dorset House, Stamford Street, London, S.E.1. The price is 42*s*.

Combustion and flame

We welcome a new scientific Journal which appears under the title *Combustion and Flame*. The Journal, which is to be published quarterly, is specially adapted for the publication of scientific papers in the field of combustion and flame and it will be issued on an international basis. The first issue contains 128 pages and the papers which appear are entitled: Stability limits of flames of ternary hydrocarbon mixtures; Ignition of dust layers on a hot surface; A photoelectric study of the light emission from carbon monoxide-oxygen thermal explosions; The slow oxidation of methane; Some properties of formaldehyde flames; Burning velocities of hydrogen cyanide in air and in oxygen; The explosibility characteristics of coal dust clouds using electric spark ignition; Self combustion of acetylene III; A cool flame phenomenon in the combustion of acetylene; Flame zone studies III.

The Journal, the first issue of which appeared in March, is edited by Dr. Bernard Lewis and Professor A. R. Ubbelohde. It is published for the Combustion Institute by Butterworth's Scientific Publications, 4–5 Bell Yard, Temple Bar, London, W.C.2. It is distributed in the U.S.A. by Interscience Publishers Inc., New York. The annual subscription is £5 5*s*. 0*d*.

British Journal of Applied Physics

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New books

Notes and comments

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Instrument transducers

By J. Thomson, M.A., D.Sc., F.Inst.P., M.I.E.E., British Scientific Instrument Research Association, Chislehurst, Kent

After dividing the problems of instrumentation into two categories, (i) the determination of what is to be measured, and (ii) the investigation of how to make the measurement, the importance of energy transformations to problems in the second category is established. The attempt is made to define the forms of energy in a manner suitable for instrument research and a chart is presented showing important physical and chemical phenomena as transformations between these forms of energy. Particular attention is paid to those transducers which provide an electric signal. In conclusion, recent developments of transducers are considered from the point of view of instrumentation and the significance of solid state science is underlined.

INTRODUCTION

industrial physicists are now beginning to take a wider st in the economic aspects of the industries they serve, y not be inappropriate to introduce a discussion of ment transducers by a short statement on the economics trumentation. In any country where mass-production rule, the case for generous instrumentation of processes achines is incontestable. This is the case in the United of America and in Russia where the home market is of magnitude that many different products have to be made nbers of the order of a million to satisfy it. In smaller mic units such as the United Kingdom the case for ve instrumentation is not so obvious for there are fewer ces where large quantities are being produced auto- ally. For that reason, while it is easy to show that the material-producing industries in this country should be nstrumented such as, for example, steel, chemicals, coal il, we must remember that a large percentage of our rial turnover is in the hands of relatively small firms facturing small quantities of specialized products, and herefore, not immediately obvious that the philosophy strumentation and automation has major economic cance.

vertheless, two additional factors must be taken into nt in assessing the importance of instrument research, pment and production in the United Kingdom. The s that we ought to be manufacturing instruments for economic units to use; and the second that there is a ood of the United Kingdom becoming part of the economic unit comprising the whole of Europe, in case mass-production of a larger variety of products e feasible. Bearing these two factors in mind, no gy need be made for insisting that it is of vital importance in the forefront in the new industrial revolution, whether ossible at the moment to see an immediate exploitation tomation in British industry or not. The fact of the r is that improvement in quality at an economic price world-wide need and with our scientific abilities and rial "know-how" there is a wonderful opportunity to s need in all quarters of the globe by means of British ments.

OBLEMS OF INDUSTRIAL INSTRUMENTATION

us assume that one of the outstanding problems which rial management has to solve at the present moment v to instrument manufacturing processes and machines so as to obtain better control of the finished product at the minimum cost. In many cases it is only after this problem has been solved that management can proceed to the second stage which has been dignified by the name "automation." The technical problems can be divided into two classes. First, the plant engineer has to discover what, in fact, he wishes to measure. This side of the problem is seldom appreciated by the academic scientist. Historically we tend to measure temperature, pressure, rate of flow, mass, length and other fundamental physical parameters, but there are very few cases where these are the measurements which give the maximum information about the process or machine. In many cases, particularly in chemical plant, the state of manufacture is such that the engineers concerned admit they do not yet know which parameters control the quality of the product or their relative importance. Moreover, at the moment quality control is generally done by tests on the final product. These tests may be subjective or objective and in a good many cases they are destructive. It is very difficult, and in many cases impossible, to feed back the information obtained from such tests so as to modify the manufacture in a reasonable time. A good example of this is to be found in the paper-making industry, where it is not yet known exactly what factors control the quality of the stock which goes to make the paper. It is known, of course, that the water content is important at each stage in the manufacture, that the ultimate size of the fibres is important, and that a combined property of these two, namely the viscosity of the stock, is a reasonable measure of a certain aspect of the quality, but it remains for the technologist to discover exactly how to control the stock so as to produce the best results from the final test. It is now widely recognized that adequate control can only be accomplished, in the first instance, by generous instrumentation and by careful analysis of the records to discover the relative importance of the parameters.

As a first step to automation, C. A. Laws has already suggested a practical system. Starting with a process plant including its instruments, some already associated with simple control loops, he proposes that the instrument readings be converted to digital form in a data-reduction machine which presents the control engineer with a compact picture of the "errors" measured by his instruments. This picture would then be used, at first manually and later automatically, to adjust the settings on the controllers. This step towards automation is modest but based on sound practical principles. In comparison with the more ambitious projected uses of computers giving over-all plant control, it affords a method of introducing automation gradually and to the satisfaction of the plant engineers. Moreover, as has been pointed out by Laws, a failure in the data-reduction loop would not, using his method, cause any catastrophic change in plant conditions. For plant analysis the scheme appears to be admirable.

The second technical problem of industrial instrumentation is to invent the right kind of instrument for the particular job. We begin here with the assumption that it is known what is to be measured. Generally there are many ways of making the measurement and this second problem is to find out which is the best. For example, there are many kinds of flow-meter based on entirely different principles.

Scientific judgment of a very high order is required to solve this problem and this scientific judgment has enormous economic significance, for once a development laboratory is launched on a particular project it can generally achieve some degree of success, but the cost will be many times greater if the wrong principle has been adopted from the outset. Time spent on assessing the possibilities of various methods of making a measurement is generally spent to good purpose. On the other hand, if the final judgment is delayed too long, a competitor will take the cream of the market with what may well be an inferior product.

Of the two problems outlined above, the first is much the more difficult. In some industries in this country it will take several years of arduous and careful work to establish the effects of parameters and how to combine the errors for control purposes. Clearly this type of work requires very intimate co-operation between plant engineers and scientists who are versed in the principles of instrumentation, and it should be noted that these scientists cannot be replaced by a man with a knowledge of existing instruments, for the latter is of little help in thinking out new methods of measuring heretofore unmeasured qualities.

It is in this respect that it is so important to appreciate the part played by the transducer in detecting elements, and it is for this reason that attention is directed to the fundamental concepts of transducer action covering all the phenomena known to natural science.

2. TRANSDUCERS

First of all, let us define a transducer. For the purpose of this discussion it is proposed to call a transducer any device in which energy is changed from one form to another, irrespective of whether there is amplification and irrespective of the mode of presentation of the result. This definition obviously covers a host of components and makes it extremely difficult to be logical and systematic in discussing them. But it is claimed that it is in this difficulty that the value of the study lies, for in attempting to systematize the study of transducers we shall undoubtedly learn much more about the nature of energy transformations. To give a very simple example of a device which changes in a limited manner one form of energy to another, consider for a moment the thermionic valve. When we use the latter as an amplifier we are inclined to be misled by the term used to denote our purpose—that is, amplification. The thermionic valve is, in fact, a device for changing one form of electrical energy to another with, of course, a whole series of concomitant effects, one of which is an "amplification" of a controlling voltage. To take another apparently simpler example of a transducer, if we make a circuit of a piece of copper wire, bonded at both ends to a platinum wire, and if we heat one junction, keeping the other at room temperature, some of the heat is transformed into an electrical current flowing in the circu Here we have an apparently simple transformation from he to electric power, but one which demands careful analy if we are to understand exactly how the energy is transforme

3. SOURCES OF ENERGY

Following on these introductory remarks, let us now back to fundamentals and ask what are the sources of ener available in the universe. Without treading on controvers ground we are safe in saying that there are three natu sources of energy. These are contained (*a*) in the nuclei atoms, (*b*) in the extra-nuclear structure of atoms and mo cules, and (*c*) in the incoherent motions of the molecules matter in bulk.

These three forms are known respectively as nuclear ener chemical energy and heat energy. In the case of both nuc energy and chemical energy, liberation is brought about w fission or fusion occurs, in each case with the evolution more stable "substances." In the case of heat energy, kinetic energy of the molecules can be made to do wo It should be noted that the words "fission" and "fusion" used here in their general sense and not as words commo technical jargon.

If one wished to be controversial, one might attemp work even further back from these three forms of ener and it might be contended that all the energy in the unive has, as its ultimate source, electromagnetic energy. To this contention value it would be necessary to prove that binding forces inside the nucleus were electromagneti nature. Although it is possible at the present time to s that this is likely, it certainly cannot be proved.

4. THE FORMS OF ENERGY

Although there are only three *sources* of energy in universe, we are accustomed in our scientific investigati to define the forms of energy in a manner more suitable our investigations. Different people would define the *for* of energy in different ways, but it is proposed to use definiti suitable for our specific purpose.

First, we have *nuclear energy*, which can give rise to hi speed particles and electromagnetic radiation of very sh wavelength. This energy is detected and measured as m or mechanical inertia, although it should be noted in pass that the measurement as carried out by a mass spectrogra always involves masses which carry electric charges.

Secondly, there is *atomic energy*, comprising the ene associated with the electronic structure of atoms and appe ing in chemical reactions. This energy is only available exchange processes and, again, and arbitrarily, elect magnetic energy and the particles which may be emitted fr the atoms and molecules are not included. It is difficult imagine any method of directly measuring atomic energy all comparable with the method of measuring nuclear ene and this in itself gives rise to interesting speculations.

Thirdly, there is *microkinetic energy*, comprising energy associated with moving charged particles by vir of their velocity and mass. We find this energy in part accelerators, in X-ray tubes and in certain forms of thermio valve. Nuclear and atomic energy are often converted i microkinetic energy in the form of fast-moving electrons positive ions.

Fourthly, there is *static electromagnetic energy* by wh derstand the energy associated with electric circuits. form comprises two sub-divisions, electrostatic and etostatic, usually represented by $\frac{1}{2}CV^2$ and $\frac{1}{2}LI^2$ respec-

This is the form into which it is most convenient to orm all other forms for instrument purposes, and l the term transducer is often used with the limited tation of a device which transforms any other form of y to the static electromagnetic form.

hly, there is *radiant electro-magnetic energy*, which is ated with variable electric and magnetic fields in free and comprises radio, infra-red, visible, ultra-violet, and γ waves. When such energy interacts with matter se sight of the electric and magnetic fields and become ious of the photon of energy $h\nu$.

thly, there is *coherent molecular energy* or *elastic energy*, iated with the elastic forces in matter in bulk. The e of this energy is, of course, chemical, but it is an recognizable form having its own significance, parti- y when one comes to consider transducers. This ent molecular energy cannot always be measured ly, although heat of crystallization determines the l energy in some cases.

enthly, there is *non-coherent molecular energy*, which is y another name for the *heat energy* associated with matter in bulk. This appears to be directly measured by a thermometer, but a little thought shows that we have merely indicated the form of the energy by making use of it in another substance.

Finally, there is the *energy associated with macroscopic mass* by virtue of its speed or position. This is the first form of energy we learn about in elementary physics, under the generic names of kinetic or potential energy. It is indeed unfortunate that our basic units of length, mass and time are derived from this gross form.

Transducers are devices which change one of the forms of energy just mentioned to another, and so it should be possible to construct a chart having the various forms of energy at the heads of eight columns and the same forms of energy at the heads of eight rows, and every physical or chemical effect shown in an appropriate square in the chart. To take simple examples, the Peltier effect transforms heat to electric energy; the Van der Graaf machine transforms electrostatic to electrokinetic energy, and so on. Such a chart has been constructed with the full knowledge that it was bound to be incomplete and almost certain to be inaccurate. The purpose in constructing it is to cause us to think more deeply about the energy interactions which form the basis of instrumentation.

	Conversion from							
Types of energy	*Nuclear*	*Atomic*	*Elastic*	*Heat*	*Static electromagnetic*	*Radiant electromagnetic*	*Microkinetic*	*Macroscopic kinetic*
Nuclear		Direct action is impossible	Direct action is impossible	Above 10^5 degrees K	Not entirely impossible	Transformations by means of gamma rays	Transformations by means of particles	Impossible in laboratory
Atomic	Radioactive transformations (a by-product)		Direct action is impossible	Thermal combination, dissociation and excitation Endothermic reaction	Stark and Zeeman effects Electric discharge	Photo-chemical reactions	Chemical change by particle bombardment	Detonation by impact(?)
Elastic	No apparent direct action	Crystal formation		Crystal formation	Piezo-electricity Ferro-electricity Magneto-striction Loud-speaker	Modifications to molecular structure	Modifications to crystal structure	Generation of elastic oscillations
Heat	No direct action, but final form	Exothermic reaction (excess)	Attenuation and super-sonic heating		Resistive losses	Absorption and degradation	Bombardment of matter in bulk	Friction and viscosity
Static lectro-magnetic	May occur but unknown	Volta effect	Piezo-electricity Ferro-electricity Magneto-striction Microphone	Peltier effect		Radio-frequency reception	Special high tension supplies	Dynamo, etc.
Radiant lectro-magnetic	Gamma radiation	Chemical excitation of radiation	Feasible by means of the three effects above	Radiation from hot body	Radio-frequency emission		X-ray tube Alpha- or beta-ray transformations with gamma emission	Possible perhaps in future
Micro-inetic	Alpha and beta particles Neutrons Mesons	Chemical ionization	An effect should be possible	Thermionic emission Molecular beam	Field emission Hall effect Particle accelerators	Photo emission Gamma-ray transformation with alpha and beta emission		Only via chemical action
Macro-copic inetic	Final product in nuclear engine	Final product in i.c. engine	Spring motor or elastic motor	Steam engine	Electric motor	Radiation pressure effects	Practical applications feasible	

5. ELECTRICAL TRANSDUCERS

In modern instrumentation the output signal is very often electrical. Although in many industrial instruments pneumatic controllers are used and a pneumatic signal is preferred, it is likely that in the future such systems will give way to electrical controllers with electrical data processing machines. It is, therefore, worthwhile to examine one row of the chart in detail, namely that concerned with transformations from other forms of energy to what has been called "static electromagnetic."

5.1. *Nuclear energy*

Examples of instruments which employ the products of nuclear disintegrations and in which the final signal is electrical are the Geiger counter, the scintillation counter and the ionization chamber. In all three cases the transformation from nuclear to static electromagnetic energy is not done directly for in the Geiger counter nuclear energy is detected by means of β and α particles; these represent microkinetic energy. The ionization produced by these particles, considerably amplified by the device, is then detected as a pulse of static electromagnetic energy. Scintillation counters are even more complex for in one of the methods of using these, the nuclear energy having given rise to a particle, that particle strikes a crystal and there gives rise to a pulse of radiant electromagnetic energy. This is then detected by a photoemissive surface, giving rise to a pulse of static electromagnetic energy. This complex chain of events begins with nuclear energy and ends with static electromagnetic energy. The amplification throughout the chain may be very large. The ionization chamber is perhaps the simplest case of all. Here the ionization produced by the particle is transformed directly into an electric current. The application of these various transducers in industry is becoming widespread. Thickness gauges are now in commercial use and the detection of flaws in heavy material can be done by similar methods. Older applications are well known.

5.2. *Atomic energy*

The transformation from atomic to static electromagnetic energy takes place directly in the primary cell, with which we have all been familiar since our schooldays. An example which is only slightly less well known is to be found in the pH meter where the atomic energy is measured directly but relatively by an electrical potential. In both cases the electrical energy is made available by the consumption of the binding energy in an ionic compound or the exchange of one state for another in which the binding energy is less. Complex transformations in which the atomic energy is first of all detected by emitted electromagnetic radiation are well known.

5.3. *Microkinetic energy*

In many applications of the thermionic valve the kinetic energy of the electrons is transformed into static electromagnetic energy in a circuit. It is true that the former has been derived from an outside generator, but the internal action of the valve is properly described as a transformation from microkinetic to static electromagnetic. All the cases mentioned under *nuclear energy* can be cited as examples in this category also, since, as was mentioned there, the nuclear energy must be transformed first to the microkinetic form before it can be detected in the Geiger counter or ionization chamber. Microkinetic energy, as its name implies, can only be a transient form. In this respect it corresponds to radiant electromagnetic and macroscopic kinetic.

5.4. *Radiant electromagnetic energy*

There are very many examples of transducers which tran form radiant electromagnetic energy to static electromagnet energy. Examples are the photoemissive cell, the phot conductive cell, the ionization chamber, and, at the oth end of the scale, the radio receiver. In the first two case mentioned, quanta of radiant energy individually alter t structure of a thin layer of material, giving rise to an electr current. In the ionization chamber the effect spread throughout the volume of a gas and again gives rise direct to an electric current. The radio receiver is in an entire different category, for here the electric field or magnetic fie associated with the radiant energy is made to produce voltage across a conductor and that voltage is then amplifi and transformed until its magnitude and character are su that it can be displayed conveniently to the eye or the e Complex forms of transducers in this category include t bolometer and the thermocouple, where the electromagnet energy is first absorbed as heat and the increased kin energy of the molecules is used to produce an electric effect.

5.5. *Elastic energy*

Once more, there are many examples of transducers. T piezo-electric crystal, quartz being a good example, transfor elastic strain into electrostatic energy. The same type action occurs in ferro-electric crystals, while in magne strictive devices the elastic strain is transformed into current flow. Ultrasonic receivers, strain gauges and accele meters are practical examples of applications of s transducers.

5.6. *Heat energy*

As already mentioned, the photoconductive cell transfor radiant heat to static electromagnetic energy. The ther electric effect is another example of the same kind, whil saturated thermionic valve may be regarded as a device which the current flow is dependent upon the temperat of the cathode. Indirectly, a dynamo operates by the ac of the hot gases or vapours via an intermediate engine which the energy is macroscopic kinetic. But the interest examples are not the obvious ones. For example, a tra sistor only operates by reason of the thermal energy sto in the crystal lattice. In this respect it is similar to thermionic valve.

5.7. *Kinetic energy*

Finally, transformations from macroscopic kinetic ener to static electromagnetic energy are to be found in all for of electric generator, but from the instrument maker's po of view digitizers are probably the most important exampl There are also the various forms of mechanical-to-electric transducers which come into this category.

6. NEW TYPES OF TRANSDUCERS

Turning now to the application of these principles instrumentation, the problem may be stated as follows. the scientist is asked to detect or measure a certain paramet his first preoccupation is to determine which energy cha offers the most likely means of making unambiguous obs vations of the parameter, separating it from other variab To measure the viscosity of a fluid what effect of the visco is the most distinctive? To measure the bubbles in a gl what effect of the bubbles enables them to be examined easily? To detect a small change in the position of a what effect of the shape, size, hardness, polish, etc., of ool can be most easily detected?

short, the scientist is required to make a search through hysical and chemical properties of materials to discover h form of energy to employ to produce the required l. Although he may wish to present an electrical signal e end-product, it is not necessary (and in general it is possible) either to start with an electrical signal or to sform directly to an electrical signal. Usually, a series ransformations must be made, each stage giving (if ible) an advantage in increasing the signal-to-noise , although the stages may be so closely interlinked a careful analysis is required to bring the intermediate to light. Examples of this kind have already been n.

general, too, an instrument transducer should embody a in amount of amplification of the signal. There are reasons for this: (*a*) that the final result should be dis- ed on an open scale, and (*b*) that the transducer should as little energy as possible from the process under nination. This amplification is liable to obscure the sducer action, for in many cases what is loosely known amplification" is not, in fact, a linear transformation but bsidiary exchange of energy. The thermionic valve has ady been cited as a good example. Others are the Geiger nter, the gas-filled photocell and the photo-transistor.

nother preoccupation of the designer of new instruments ith the natural noise level of the detecting element. rmal noise and shot noise in electronic devices are fairly understood, but it is not at all clear what the natural kground is likely to be in many detecting elements. For nple, in weighing, where the preferred method is to pare the weights of two masses, it is difficult to assess the ural limit, probably because that limit is so far beyond the ent practical balance. In general terms the Brownian ement defines its theoretical value, but it is likely that r factors will raise this theoretical level in particular s.

7. THE DEVELOPMENT OF TRANSDUCERS

Much of the inventive effort of the present epoch is being spent on the development of new transducers, and in many cases these are directly linked with static electromagnetic energy. For example, the last decade has seen enormous strides in the development of crystal diodes, photoconductive diodes, transistors and photo-transistors. Although these are not yet in full industrial use, enough has been accomplished to make it easy to prophesy their general application. Ferrite devices are now being developed in the same way. Magnetic stores of varying types have been tried experimentally and in some cases have reached full-scale production. In the case of these magnetic elements it is equally safe to prophesy a great future. At the same time ferro-electric devices are becoming commonplace and are displacing the older piezoelectric elements. On the optical side crystal luminescence is emerging from the research stage. Enough is now known of the properties of thermo-, photo- and electro-luminescent substances to enable one to predict much more general industrial applications for devices which incorporate them, quite apart from the possible advances in colour television. The properties of thin films are coming under expert scrutiny at a time when there is a much better understanding than ever before of the chemical and other bonds determining their structures. Thin films can produce for us a new generation of transducers, but only when their behaviour is well understood and their relation to various substrates under control.

An examination of the preceding paragraph indicates the extent to which the physics and chemistry of the solid state have grown in technological significance in recent years, for the examples given have not been chosen to demonstrate this fact, but to represent real achievement. It is certainly to solid state science that we must look for the greatest advances in the future. In addition to the many instances where solid devices have already displaced their gaseous and vacuum counterparts, we can look forward to many things being made possible for the first time by their use. If the first half of the twentieth century was dominated by thermionics, the second half looks like being dominated by the science of the solid state.

ORIGINAL CONTRIBUTIONS

A water-cooled mercury arc lamp for the excitation of Raman spectra

By L. A. Woodward, M.A., Ph.D., and D. N. Waters, B.A., Inorganic Chemistry Laboratory, University of Oxford

[*Paper received* 14 *January*, 1957]

A modified Toronto-type mercury vapour lamp, suitable for the excitation of Raman spectra, is described. It is constructed throughout of Pyrex and is water cooled, not only at the electrodes, but also along the whole length of the arc (approximately 185 cm). An inverted-U shape is adopted, so as to allow free expansion of the inner arc tube relative to the cooling jacket and thus render expansion bellows unnecessary. Current-voltage characteristics are given for the range 10–32 A. The intensity of emission of each of the mercury lines 4046, 4358 and 5461 Å is determined by photographic spectrophotometry as a function of lamp current or wattage. For a given current the light output is found to be slightly lower when the lamp is running with full cooling than when it is running as an ordinary Toronto arc with cooling of the electrodes only; but with full cooling higher currents can be used and thus greater light outputs attained. However, the rate of increase of intensity with increase of current is found to fall off at higher values; so that, for a given wattage, a single lamp gives less light than several in parallel.

By far the most widely used light source for the excitation of Raman spectra is the mercury vapour arc. The very intense blue line (4358 Å) is especially suitable, as there is a fairly wide region on its long-wave side that is conveniently free from other primary lines. The intense violet and green lines (4046 and 5461 Å respectively) are also useful for Raman excitation. Commercial mercury arc lamps, which run at comparatively high vapour pressures, suffer from the disadvantage that the line spectrum is accompanied by a continuum which, although relatively weak, may mask Raman lines. A notable advance was the development of the so-called Toronto arcs⁽¹⁾ with water-cooled mercury pool electrodes. These lamps give a much "cleaner" and more satisfactory spectrum, in that the cooling keeps the mercury vapour pressure low and so reduces the intensity of the otherwise troublesome continuous spectrum. A further advantage is that the intensity of the blue line (4358 Å) relative to its weaker close companions is much enhanced. Toronto arcs constructed of Pyrex glass are normally run at approximately 15 A. Attempts to increase the light output by raising the current further are likely to cause failure by softening of the glass envelope.

For the excitation of weak Raman spectra (especially of gases) sources of the highest possible light output are required. The most recent advance in this direction is the introduction by Stoicheff⁽²⁾ of water cooling along the whole length of the mercury arc, as well as for the electrodes. The extra cooling makes it possible to use higher currents (e.g. 30 A or more) with a consequent increase of light output. Lamps of this kind have been described also by Welsh *et al.*⁽³⁾ and (briefly) by Shull.⁽⁴⁾ There is, however, a discrepancy between the statements of Stoicheff⁽²⁾ and the findings of Welsh *et al.*⁽³⁾ concerning the light output in comparison with ordinary Toronto arcs. In the present paper a fully cooled lamp of somewhat modified form is described and its voltage-current and intensity-current characteristics are given, both for operation with full cooling and also for operation as an ordinary Toronto arc with only the electrodes cooled.

DESCRIPTION OF LAMP

Previously described lamps with water cooling along the whole length have been of the "straight" type, either horizontal (Stoicheff⁽²⁾) or vertical (Shull⁽⁴⁾). In both designs it was necessary, in order to prevent shattering du to differential thermal expansion, to construct the cent cooling jacket with suitable flexible "bellows." By a simpl modification of design the necessity for such devices has been eliminated in the vertical lamp shown in Fig. 1. It is constructed throughout of Pyrex. The inverted-U shape, with both electrodes at the bottom, permits of free expansion o the inner arc tube relative to the outer water-jacket. Th design simplifies the construction and eliminates sources o mechanical weakness. It also reduces the overall dimension so that, when several lamps are incorporated in a Raman excitation unit, the enveloping reflector can be made smaller with consequent increase of efficiency (see Busing⁽⁵⁾).

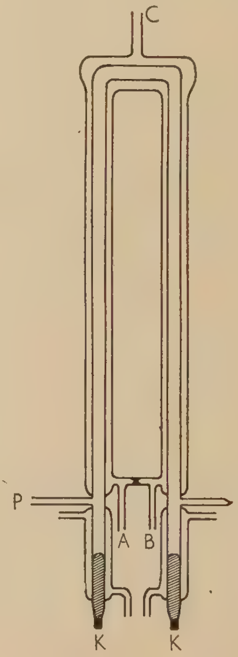

Fig. 1. Water-cooled mercury arc lamp for excitation of Raman spectra

he internal diameter of the arc tubing is approximately nm and the length between the mercury surfaces approxi- ely 185 cm. Connexion of the d.c. supply to the mercury ls is by means of the Kovar cups *K*, *K* which are joined to envelope by graded seals. During running the pools are t at approximately room temperature by a rapid stream water through the electrode cooling jackets. For the ting of the lamp (see below) the water passing through se jackets can be heated almost to boiling point. The tral cooling jacket of the arc has two independent water ts *A* and *B* and a single outlet *C* at the top. It forms part a closed circulatory system, including a water reservoir an impeller pump. During running the water temperature he jacket is kept at about 60° C. In order to get rid of heat generated in the lamp, the reservoir of the circulatory em is fitted with closed cooling coils, through which an iliary stream of cold water can be passed.

s is well known, the lighting of Toronto arcs is occasion- troublesome. With the lamp shown in Fig. 1 the follow- procedure has been found advantageous. Water at about 95° C is first passed through the two electrode jackets, the water circulating through the central jacket is also ed to about the same temperature. (For this purpose the rvoir of the closed circulatory system is fitted with electric ersion heaters.) The d.c. supply is then applied to the ar electrodes, and the secondary terminals of an induction (gap about 1 in.) are connected to a pair of aluminium bands wrapped around the vertical limbs of the lamp, near each electrode. The induction coil is switched on, finally a tesla leak-tester is held in the spark gap. This ally causes the lamp to light up. Thereupon the induction is switched off, cold water is immediately passed through electrode jackets, and the water circulating through the ral jacket is adjusted to about 60° C by changing over n heating to cooling in the reservoir. Occasionally, when lamp does not light at once on application of the Tesla, possible to overcome the difficulty by the simple expedient eversing the polarity of the main electrodes.

he lamp is kept permanently connected to the pumps ugh the side-arm *P* (see Fig. 1). It is our practice to keep pumps running while the lamp is alight, though this does appear to be essential.

ELECTRICAL CHARACTERISTICS AND LIGHT OUTPUT

view of the discrepant reports of previous workers, the rating characteristics of a lamp of the type described ve were investigated in some detail. The voltage across electrodes could be varied at will, either by adjustments e d.c. generator which supplied the power or by alteration resistance placed in series with the lamp. Fig. 2 shows voltage drop in the lamp as a function of the current ing. The unbroken curve is for the fully cooled lamp extends up to the highest current used, 32 A. The ken curve gives the corresponding results for the same running without water in the central jacket, i.e. as an nary Toronto arc with only the electrodes cooled. The es represent the static or equilibrium characteristics. It found, however, that a sudden alteration of applied age (as effected, for example, by shorting out a portion he series resistance) resulted in an almost instantaneous ge in the current to the new static value. The lamp d therefore be operated stably without a series ballast tance.

The important practical question of the dependence of light output upon current or wattage was investigated by measurements of the intensities of each of the three mercury lines (4046, 4358 and 5461 Å) principally used for the excitation of Raman spectra. For each of a series of steady currents the emitted spectrum was photographed with the same exposure time, using a type E 612 two-prism Raman spectrograph (by Hilger and Watts Ltd.). A wide slit was used so that the photometer trace of each line was "flat-topped." On the same plate and with the same exposure time was also photographed a set of comparison spectra with known relative intensities, obtained by means of a Hilger step filter placed at the spectrograph slit. Densities were determined with a recording microphotometer and characteristic curves for the plate at each of the relevant wavelengths were constructed in the usual way. The intensities for each of the three mercury lines were then determined by interpolation. Rather similar measurements have been made by Welsh *et al.*,$^{(3)}$ but these workers used gelatine filters to isolate the mercury lines and then measured their intensities photoelectrically.

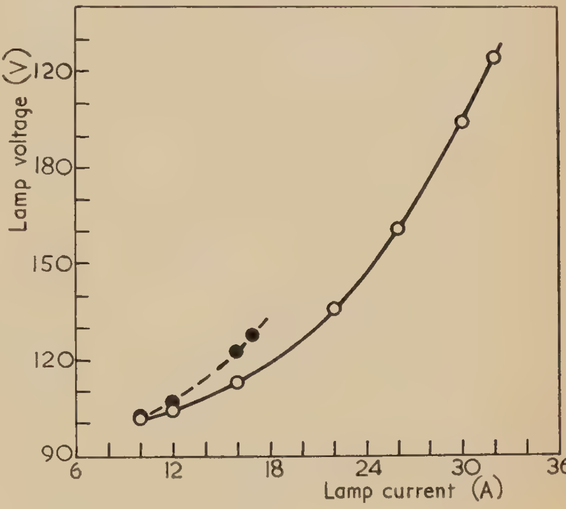

Fig. 2. Voltage-current characteristics

Unbroken curve, envelope cooled; broken curve, envelope not cooled.

Our results are shown graphically in Fig. 3. For each of the three mercury lines the intensities were measured on a different arbitrary scale, and no attempt was made to relate these scales to one another. In Fig. 3 it is seen that the intensities of both the blue line (4358 Å) and the green line (5461 Å) are plotted on a common scale; but this is achieved by arbitrarily setting the intensity for both lines equal to 100 for the fully cooled lamp running at 22 A (see unbroken curves of Fig. 3). The corresponding curve for the violet line (4046 Å) was found to be nearly coincident with that for the blue line (4358 Å): it is omitted from Fig. 3 for the sake of clarity. The broken curves of Fig. 3 show analogous results, on the same intensity scale, for the lamp when running without water in the central jacket, i.e. as an ordinary Toronto arc. Again the curve for 4046 Å was practically coincident with that for 4358 Å.

From Fig. 3 it is seen that for each line the intensity increases with the lamp current, but that the rate of increase becomes less as the current rises. This falling off is more pronounced for the blue and violet lines than for the green

(5461 Å). It is noteworthy that, over the whole of the comparatively short range of currents at which it could be investigated, the lamp when running as an ordinary Toronto arc gave a slightly greater intensity than when cooled along its whole length. In this respect our results are in harmony with the findings of Welsh *et al.*,(3) and do not agree with the statement of Stoicheff(2) that the intensity of the blue line from a fully cooled lamp at 15 A is about four times greater than for an ordinary Toronto arc at the same current.

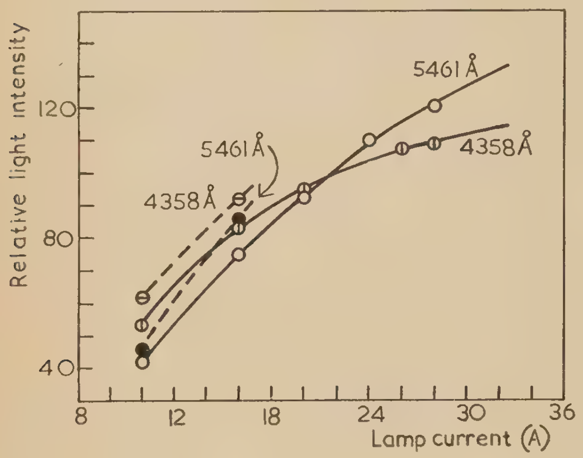

Fig. 3. Dependence of intensities of mercury lines on lamp current

Unbroken curves, envelope cooled; broken curves, envelope not cooled.

It is this clear that cooling the arc does not of itself enhance the light output; indeed it slightly reduces it. The advantage of the cooling lies in the fact that it permits the use of higher currents, which would otherwise cause the lamp to fail owing to collapse of the glass envelope; and that the consequent increase of intensity more than offsets the small diminution due to the cooling. As we have seen, however, the rise of light output with current is not linear: successive equal increments of current yield progressively smaller increases of intensity. By combining the results of Figs. 2 and 3 we may calculate the dependence of light output upon the wattage consumed in the lamp, rather than upon the current passing through it. The departure from linearity (see Fig. 4) is then even more marked. Incidentally it is seen that, for a given power consumption, the intensity of the cooled lamp does not differ significantly from that of the uncooled lamp.

From a consideration of Fig. 4 it follows that, for a given total power consumption, a greater light output can be obtained by sharing the power between a number of similar lamps than by dissipating it all in one. Suppose, for example, that the total power consumption is fixed at 5 kW. Then for arrangements using one, two, three or four lamps the total intensities of the blue line (4358 Å) would be approximately proportional to 1, 1·7, 2·2 and 2·5 respectively. In practice, of course, other factors play a part in determining the optimum number of lamps for a Raman excitation unit, especially the requirement that the reflector enclosing them shall be kept as small in area and as free from openings as possible. Incidentally it may be noted that the use of fully cooled lamps simplifies the problem of the regulation of the temperature of the sample whose Raman spectrum is being investigated.

As far as quality of spectrum is concerned, the fully cooled lamp appears to have all the virtues of the ordinary Toronto arc; but unfortunately it likewise has the disadvantage that the Pyrex envelope gradually darkens with use. This undesirable effect is worse at higher currents;(3) so that here again there is an advantage in using several lamps each at a moderate amperage, rather than a single lamp carrying the whole load. Provided that the current is limited to about 25 A, the useful life of a fully cooled lamp (before it mus be dismantled for cleaning) may be reckoned as two o three hundred hours. (In our experience a satisfactory cleaning agent is 5% hydrofluoric acid to which has been added a little detergent (Teepol). The use of nitric acid is to be avoided owing to attack on the Kovar.) So long as the envelope is made of Pyrex, it seems that this is about the best performance that can be achieved. An improvement might result from the use of a special glass.

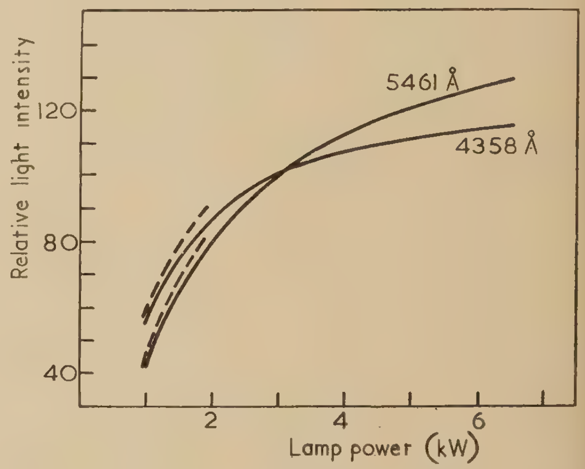

Fig. 4. Dependence of intensities of mercury lines on power consumed in lamp

Unbroken curves, envelope cooled; broken curves, envelope not cooled.

In conclusion we should like to pay tribute to the skill of the laboratory's glass-blower, Mr. G. Wilkinson, and to thank him for his invaluable co-operation on the constructional side.

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An apparatus giving thermogravimetric and differential thermal curves simultaneously from one sample

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A description is given of modifications to a Chevenard thermobalance which enable it to record simultaneously, but on separate charts, both thermogravimetric and differential thermal curves of a single sample undergoing thermal decomposition. A method of placing temperature marks on both charts is also described. Some records obtained and the performance of the apparatus are briefly discussed.

alytical methods that are used to record reactions urring during thermal decomposition of a material are erential thermal analysis (D.T.A.), thermogravimetric lysis (TG.A) and differential thermogravimetric analysis TG.A). D.T.A. records thermal reactions which occur various temperatures during decomposition and is widely d as a qualitative method of examining materials. Phase npositions can also be studied by comparing peak areas nknown materials in a D.T.A. curve with those of standard terials. However, the degree of crystallinity of a material cause a wide variation in the area of peaks on the D.T.A. ve, and since this variable is not always known the accuracy a determination is often doubtful. Despite this limitation, T.A. provides one of the few means of estimating the ount of a particular phase produced by a reaction not olving a change of weight. On the other hand, TG.A, ich provides a continuous record of weight changes during rmal decomposition, is a more reliable and more con- ient quantitative method where a reaction is accompanied a change of weight. Where a reaction is shown by only nall inflection on the mass-temperature curve, a differential t of the TG.A curve is necessary to define accurately the nperature and hence the composition at which the reaction urs. All three methods used simultaneously provide the ximum amount of information to be obtained from a single rmal decomposition.

t has been pointed out$^{(1, 2)}$ that D.T.A. and TG.A compli- nt each other, and a method has been developed to record T.A. and TG.A curves simultaneously on one chart by ting a separate sample for each analysis within one furnace. nultaneous recording of curves makes it possible to relate accurately the thermal effects and changes of ght produced by a particular chemical reaction. This relation confirms phase changes which otherwise might be doubt, and also makes it possible to determine the com- ition of the phases, the formation of which is clearly wn by the peaks on the D.T.A. curve, and hence a more urate interpretation of the thermal decomposition can be en.

The author has been able to obtain all three records from ingle sample by simultaneously recording the two funda- ntal curves, D.T.A. and TG.A, and then using a graphical thod of differentiating the TG.A curve. An automatic tting method could be used,$^{(3, 4)}$ but the extra equipment uld be costly and graphical differentiation has proved te satisfactory.

MODIFICATION OF THE APPARATUS

The modification to be described was carried out on a otographic-recording Chevenard thermobalance$^{(5)}$ but could also be applied to the pen-recording instrument. The main items of auxiliary equipment necessary were a Kent

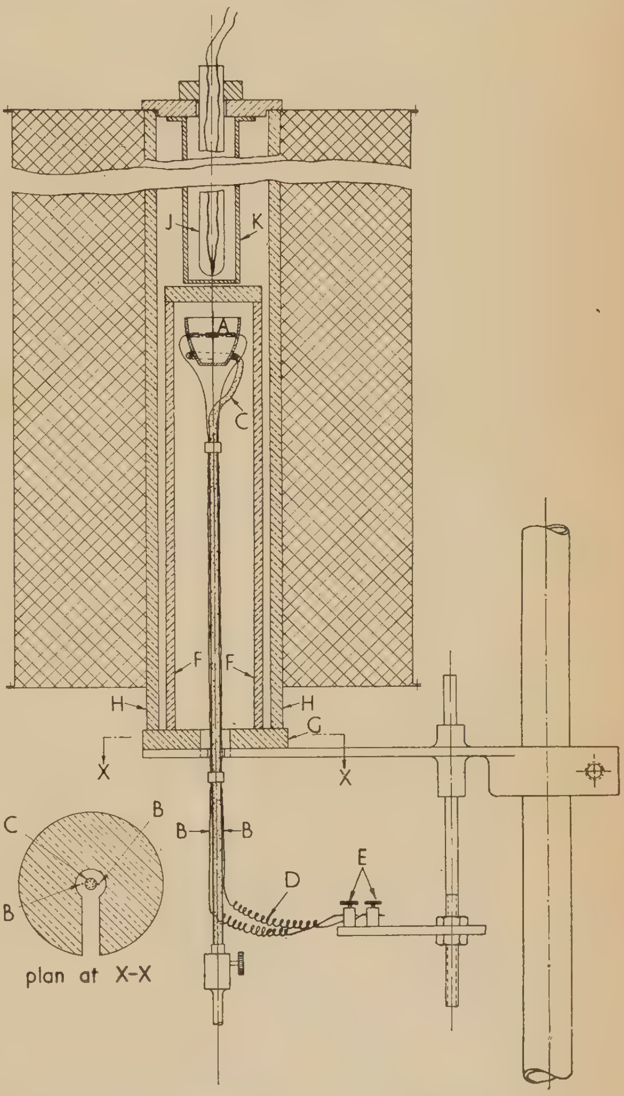

Fig. 1. Section of the furnace showing sample holder assembly, inner ceramic tube and furnace thermocouple sheaths

A, sample holder; *B*, 0.02 in. platinum thermocouple leads; *C*, crucible holder of the thermobalance; *D*, 0.005 in. spiralled platinum leads; *E*, terminal block; *F*, inner ceramic tube; *G*, lower furnace stop cover; *H*, furnace tube; *J*, silica sheath; *K*, stainless steel sheath.

single-point recording potentiometer used to record the furnace temperature, a Gall (Tinsley) amplifier, and an Evershed and Vignoles pen-recording milliammeter used respectively to amplify and record the differential temperature.

Construction and operation of the sample holder assembly. The construction of the sample holder assembly is illustrated in Fig. 1. The sample holder *A* consisted of a ceramic crucible, $\frac{7}{8}$ in. diameter and $\frac{5}{8}$ in. high, divided into two compartments by a piece of platinum foil held in a groove in the sides and bottom of the crucible. Differential temperatures were measured by means of a thermocouple *B* which was made by welding pieces of pure platinum wire (0·020 in. diameter and about 10 in. long) to each side of a $\frac{5}{16}$ in. length of platinum/13% rhodium wire of the same diameter. The differential thermocouple was passed through small holes about 0·02 in. diameter in the side of the sample holder until the thermojunctions were at the centres of each compartment. Three small insulators within the sample holder prevented movement of the thermojunctions when once positioned. The sample holder was then placed in a crucible holder *C*, which was made from $\frac{1}{8}$ in. silica rod and consisted essentially of a silica ring $\frac{5}{8}$ in. internal diameter welded to a 12 in. length of silica rod with a $\frac{5}{16}$ in. offset, so that the centre line of the rod coincided with the centre of the silica ring. Small twin insulators to take the thermocouple leads were fixed at two extreme positions on the vertical silica rod by tying with fine nichrome wire. A light flexible connexion between balance and terminal block was made by means of fine-spiralled platinum wires 0·005 in. diameter (*D*) welded to the heavier gauge platinum wire on the silica rod and held in spring-loaded clamps at the terminal block *E*. To add the sample the fine platinum wires were released at the terminal block and the sample holder assembly removed from the balance and placed in a stand. The weighed sample was brushed into one compartment of the sample holder *A*, and about 1 g of inert material (alumina preheated to 1400° C to prevent re-adsorption of small amounts of moisture) placed in the other compartment. Some alumina was placed over the sample so that both the inert material and the sample could be lightly tamped without loss of sample. Since the maximum permissible load on the balance was 10 g, the weight of the sample holder and thermocouple leads was kept to about 5 g, and this allowed a total of about 5 g for sample and inert material.

Arrangement within furnace. It was found at first that movement of the sample holder as the sample changed in weight caused uneven heating of the thermocouples, and some difficulty was experienced in obtaining satisfactory D.T.A. curves. This was overcome by enclosing the sample holder in an inner ceramic tube *F* which equalized the distribution of heat to each thermojunction, over the range of movement of the sample holder.

The inner ceramic tube *F* was $6\frac{3}{4}$ in. high, $1\frac{1}{4}$ in. internal diameter and $\frac{1}{8}$ in. wall thickness. It rested on the lower furnace stop cover *G* and projected about $\frac{1}{4}$ in. above the crucible at its highest point of travel. The air gap between furnace wall and the ceramic tube was about $\frac{1}{8}$ in. and the clearance between the sample holder and the ceramic tube was about $\frac{3}{16}$ in. The ceramic tube was easily moved so as to centralize the crucible within it; while making this adjustment a mirror was used to view the crucible. It was found necessary to use a cover on the ceramic tube to prevent buoying up of the sample holder by convection currents passing through the relatively narrow gap between the sample holder and the ceramic tube.

RECORDING OF DIFFERENTIAL TEMPERATURES AND MARKING OF FURNACE TEMPERATURES ON CHARTS

A modification of the method of Carthew and Cole$^{(6)}$ was used to record differential temperatures and to mark furnace temperatures on the charts. The output from the differential thermocouples was amplified by a Gall (Tinsley) amplifier and recorded on an Evershed and Vignoles recording milliammeter, which had been modified to give a chart speed of 4 in. per hour so that this chart and that from the thermobalance would have the same time scale and so could readily be compared. A variable shunt resistance was used on the recorder so that full-scale chart deflexions could be made to represent 100, 200 or 400 μV input to the amplifier. As the amplifier would accept only a positive e.m.f. a constant potential was applied to the input so that both positive and negative voltages produced by exothermic and endothermic reactions could be recorded.

The furnace of the Chevenard thermobalance was heated at a rate of 10° C per minute. Furnace temperatures were measured by means of a platinum/platinum-10% rhodium thermocouple sheathed in a silica tube *J* and placed close to the sample in the furnace; the silica tube was enclosed in a second tube *K* made from heat-resistant stainless steel and

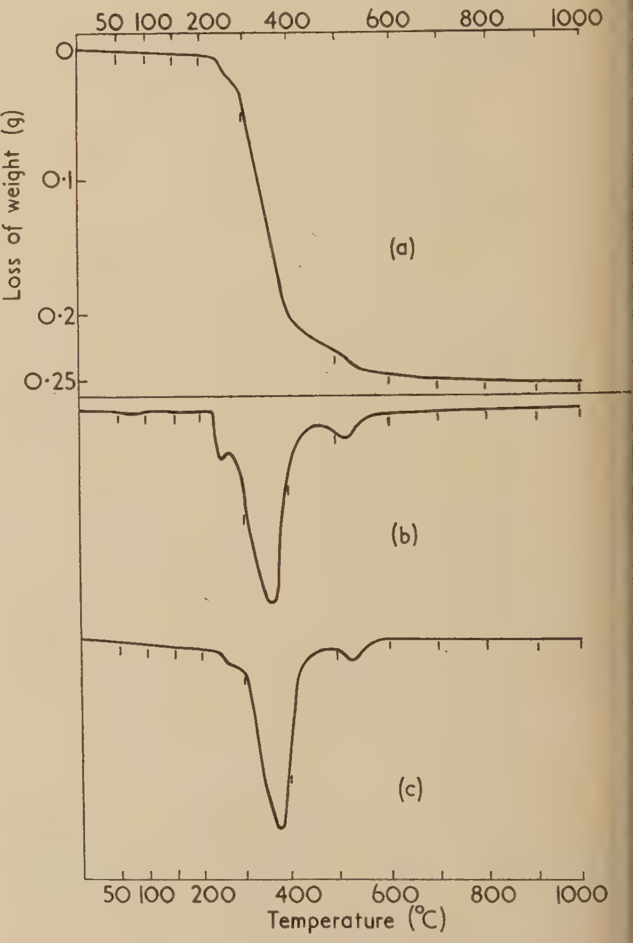

Fig. 2. Thermograms for bauxite

(*a*) thermogravimetric curve; (*b*) differential thermogravimetric curve (graphical); (*c*) differential thermal curve.

A sample weight of 0.800 g was used and prior to analysis the sample was stored at 65% r.h. and 21.1° C for several days.

ded to a metal furnace cover of the same material so that resistance of heat flow to both thermocouple and sample ıld be about the same.

'o mark the furnace temperatures on the charts a 5 in. neter cam was fitted to the potentiometer slide wire shaft a Kent recorder which recorded the output from the mocouple. Small projecting arms were fixed to the cam that movement of the slide wire shaft and cam with easing temperature caused the arms to depress a micro:ch at each 100° C to 1000° C, and also at temperatures 0 and 150° C. Depression of the micro-switch energized electronic relay which held down two sets of contacts ultaneously for seven seconds. A variable delay could be provided. One set of contacts closed an 8 V circuit he thermobalance and caused an electromagnet to withv a metal slide exposing a small slit which allowed light mpinge on the photographic recording chart. The other of contacts altered the shunt resistance of the recording iammeter and changed the sensitivity of the instrument, sing the pen to trace a line on the chart at right angles to base line. In this way temperature marks were recorded ultaneously and on the same scale on each chart; it was ı possible to transfer both curves and a plot of the G.A curve on to one chart to obtain a complete record lustrated in Fig. 2.

DISCUSSION

multaneous D.T.A. and TG.A curves (Fig. 2) were ined with the modified equipment, using a standard ple of bauxite distributed by MacKenzie and Farquon.(7) The thermal effects shown by D.T.A. [curve (*c*)] the changes of weight of TG.A [curve (*a*)] can be ırately identified in a most striking manner by a comson of the D.T.A. curve and the D.TG.A curve (*b*). The ıl convention which is used to show endothermic peaks he D.T.A. curve has been used in plotting the D.TG.A e, so that maximum rates of decomposition appear as ghs and minima as crests on the curve. The similarity he D.T.A. and D.TG.A curves has already been mened by De Keyser.(8) Owing to the thermal inertia of the em, the peaks shown on the D.T.A. curve occur at peratures approximately 10° C higher than for the esponding peaks on the D.TG.A curve, which define the t temperature of the maximum and minimum rates of mposition. The D.TG.A curve therefore gives more ırately than the D.T.A. curve the temperature at which hase composition may be determined from the TG.A e. Hence the compositions of the phases shown by s on the D.T.A. curve are best deduced from the rmation provided jointly by the other two curves. By g D.TG.A and TG.A in this manner to interpret D.T.A. curve, not only can related information from independent sources be studied and checked, but a plete picture of the thermal decomposition can be n.

s a check on the accuracy of the thermobalance with mocouple leads attached, a thermogravimetric curve of um oxalate was obtained (Fig. 3). Measured losses for reaction indicated by the curve were identical with ılated values. Variations in the distance between caliion marks on the chart for each 0·1 g were negligible, ving that the slight flexing of the spiralled thermocouple s did not appreciably effect the load on the balance although the sensitivity of the instrument was reduced from 2·43 to 2·58 mg/mm.

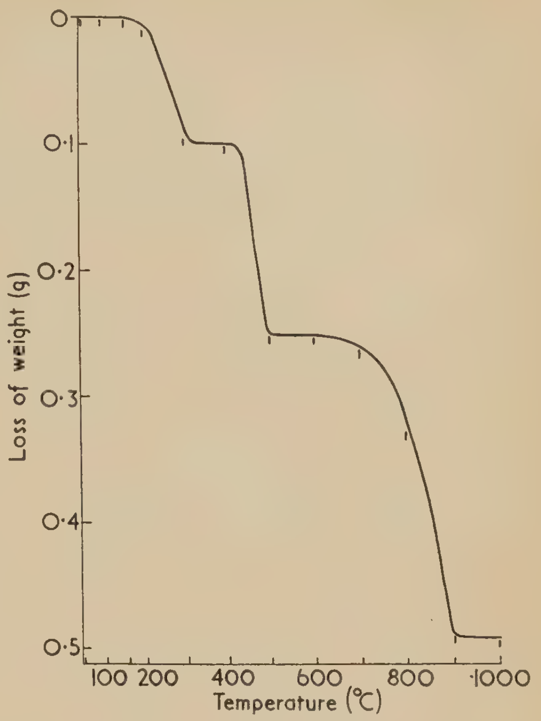

Fig. 3. Thermogravimetric curve of calcium oxalate, obtained in the combined apparatus using a heating rate of 10° C per minute and a sample weight of 0·800 g

The sensitivity and reproducibility of the differential thermal curves were quite satisfactory and the use of an inner liner in the furnace proved successful in maintaining an even heat flow to each thermocouple.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. E. H. Waters and Dr. W. F. Cole for helpful advice during the modification of the Chevenard thermobalance, and also Mr. A. E. Holland who made the special sample holder.

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Single crystal oscillation photographs about three crystallographic axes from a single setting on a Weissenberg camera

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The paper gives the design of a cam and its mounting to enable oscillation photographs to be taken about the three crystallographic axes from a single crystal setting. The modification is particularly useful with crystals of radioactive substances or those having undeveloped faces.

In determining the unit cell dimensions of single crystals it is sometimes necessary to take rotation or oscillation photographs about all three crystallographic axes. When the ordinary two-arc goniometer head is used the crystal is usually mounted three times so as to rotate in turn about the three crystallographic axes. For very small or rare crystals this may be difficult and the resetting involves a danger that the crystal may be lost. This procedure is particularly difficult if the crystal has no clear faces by which an optical setting may be made. In the case of crystals of radioactive substances it is clearly desirable to reduce handling to a minimum.

From the moving film photograph taken on a Weissenberg camera it is generally possible to measure the lengths of two sides of the reciprocal unit cell in addition to the length of the side of the direct lattice cell which is parallel to the axis of rotation. When glide planes occur it may be necessary either to take higher layer-line Weissenberg photographs or to take oscillation photographs about the individual crystallographic axes.

Mackay$^{(1)}$ has described a goniometer head which carries three extra spindles for the arcs. After setting the crystal correctly in the usual way, the whole goniometer head could be moved to one or other of the three alternative spindles. These spindles enable the crystal to be set so that its new axis of rotation is perpendicular (within 2°–3°) to the original axis of rotation. Gross$^{(2)}$ has designed a goniometer head which is claimed to possess several advantages over Mackay's design.

While using a type S-35 Weissenberg goniometer (by Unicam Instruments Ltd.) it occurred to the authors that there should be no difficulty in taking oscillation photographs about all three crystallographic axes with one setting of the crystal. The possibility of doing this does not apply to triclinic crystals. If a monoclinic crystal is mounted on the two-arc goniometer head so as to rotate about the *b*-axis (horizontal) then it is possible to bring the *a*- or *c*-axis vertical. The whole unit supporting the track, along which the camera runs, is then oscillated about the pivot in the base of the instrument. (The track is rotated about this pivot and clamped in a given position when taking equi-inclination photographs.) An oscillation photograph is thus obtained giving the layer-line separation corresponding to *a*- or *c*-axial lengths. Orthorhombic crystals may similarly be mounted with any crystallographic axis parallel to the horizontal axis of rotation of the instrument and then oscillated in turn about the other two crystallographic axes. It is convenient to take the photographs on a flat plate placed 3 cm from the crystal.

A cam of the form shown in Fig. 1 is mounted on the main axis of rotation of the instrument as indicated at *A* in Fig. 2. The working part *xy* of the cam presses against the roller *B* which is supported by an arm *C* as shown in Figs. 1 and 2. The arm *C* is held on to the base of the goniometer with a *G*-clamp, though it could with advantage be screwed i position. By this arrangement the cam oscillates the crysta about a vertical axis through an angle determined by the siz and shape of the cam. During this oscillation the clampin nut which is used to hold the track at a given angle to th incident X-ray beam must be loosened. The flat film-holde is mounted normal to the incident beam and is carried on V-slide. This slide is attached to the upper platform of th microscope support. The V-slide permits the adjustment c the crystal-film distance.

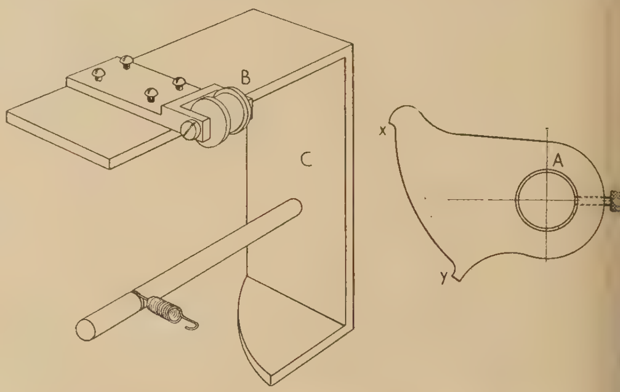

Fig. 1. Diagram of accessories for goniometer

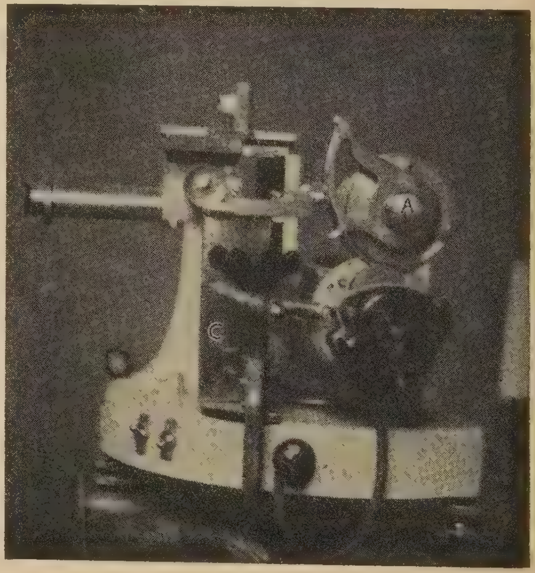

Fig. 2. Arrangement of accessories on goniometer

Vhen crystal faces are well developed so that a crystallo- ohic axis can be identified optically, the above procedure rs no difficulty. If, however, faces are not developed and orientation has been carried out by an X-ray method, a ntly different procedure is necessary. For instance, a noclinic crystal is mounted with its *b*-axis parallel to the n horizontal axis of rotation of the instrument. A zero- r photograph is taken. Before removing the camera from instrument the beam trap is removed and the direct X-ray m is allowed to fall on the film for a short time. The ling of the graduated drum giving the setting about the main axis is noted at this time. Measurement of the developed film and a simple calculation gives the drum reading for which a particular crystallographic axis is vertical. An oscillation photograph can now be taken about this axis on the flat film and the axial length can be calculated from the layer line distances.

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An automatically recording vacuum balance

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The apparatus described can record changes in weight of a solid, either in the presence of a gas or *in vacuo*, at temperatures of up to 1000° C, to an accuracy of ±0·2 mg with a total range of approximately 5 g. Simplicity in construction is achieved by use of only standard radio and electrical components. Applications include thermogravimetric analysis, gas sorption and studies of gas-solid reactions.

desirability of having an apparatus capable of recording ll changes in weight of a solid, both in the presence of a and in vacuum, has long been appreciated. This has been hasized[1] by the growing use of the electromagnetic tion balance,[2, 3] i.e. for the determination of vapour tion isotherms, the study of gas-solid reactions and mogravimetric analysis.[4,5] The recorder of Gregg and tle,[6] devised for use with an earlier model of this nce,[7] was capable of following changes of weight to in ±0·5 mg and had a total range of 300 mg. However, n changes were only recorded after a finite displacement ne balance beam, so that a stepwise graph was obtained; hermore a very long optical lever was required neces- ing operation in a darkened laboratory. A later model,[8] n which the present recorder was developed, did produce ntinuous graph (of weight against time) but was somewhat y, and still involved a complicated damping circuit the long optical lever.

he present apparatus, in its simplest form, records changes eight to an accuracy of ±0·2 mg with a range of 220 mg, a simple attachment (described later) enables the range e extended to about 5 g. The graph of weight against is continuous; also the apparatus is independent of room ing conditions, and of moderate fluctuations in mains ly voltage.

he electromagnetic sorption balance, described in detail vhere,[9] consists essentially of a glass balance arm oorted in a glass cradle by steel needle bearings. Glass ups are mounted on both ends of the balance arm, and y connecting rods supporting the bucket and the magnet. null position of the arm is maintained by passing a ent through a solenoid surrounding the magnet, any ation from the null position being indicated by a suitable cal device. In the present apparatus (Fig. 1) the null tion is maintained automatically. Light from a projector nted vertically above the balance case is reflected by a plane mirror so as to fall equally on the cathodes of two ocells (1, 1′). Each photocell is connected via a stabilized er supply unit (2, 2′) to a time base circuit (3, 3′), such that a relay switch closes with a frequency proportional to the amount of light falling on the cathode. The two switches connect the forward and reverse circuits respectively, of a low inertia motor causing a wiper to drive along a linearly wound potentiometer coil R_p. The voltage on the wiper is fed into a linear d.c. amplifier (4), the output from which flows through the solenoid surrounding the balance magnet. Directly the null position of the balance arm is disturbed, more light falls on one photocell. The frequency of one time base now exceeds that of the other, and the wiper is driven along the potentiometer, so altering the input voltage to the amplifier. The change of current through the solenoid then restores the balance to its null position. Changes in weight are registered by the position of a pen carried by the potentiometer wiper, and are recorded on a graph. To eliminate the effect of fluctuations in mains supply voltage, the two control circuits (2, 3) and (2′, 3′) are made identical. As the rate of movement of the carriage motor is proportional only to the difference between the frequencies of the time

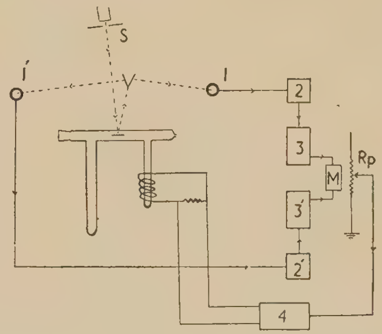


Fig. 1. Block diagram of the apparatus

1, 1′, photocells; 2, 2′, photocell supply units; 3, 3′, timebases; 4, d.c. amplifier; *M*, potentiometer motor; *S*, optical stop; R_p, potentiometer winding.

bases, any variations in mains voltage leaves the position of the potentiometer wiper unchanged.

Each of the sections 1–4, shown in Fig. 1, will now be described in detail.

THE OPTICAL SYSTEM

The essential feature of the optical system is a split mirror which varies the amount of light falling on the photocell cathodes in sympathy with movement of the balance arm without appreciably changing the position of the images. Thus, a very large proportion of the cathode area of the photocell is kept illuminated, and a maximum sensitivity is obtained.

A 12 V 48 W bulb mounted 18 in. above the balance case is used as the light source, the intensity being adjusted by a series rheostat. The light is first converged through a lens of short focal length, then passed through an optical stop *S* and falls almost normally on the plane mirror carried by the balance arm. In this way light scattering by the balance case is largely eliminated. The reflected beam now falls on the adjoining faces of the plane split mirror, and is focused to a diffuse image on the cathodes of the photocells (1, 1′). Movement of the balance arm therefore varies the amount of light falling on both the photocells. Slight dispersion of the light does occur, but correction for the fact that photocells are not equally sensitive to red and blue light can be made by adjusting the standing frequency of the time bases (*vide infra*).

THE CONTROL UNIT

The control unit (Fig. 2) consists of two distinct sections: a photocell unit (2, 2′ in Fig. 1) which alters the frequency of a very low frequency Puckle time base (3, 3′ in Fig. 1) in proportion to the amount of light reaching the photocells.

The photocell unit utilizes a Mullard 20 CV photocell with an anode potential of 120 V, stabilized by a valve type OA2. As the amount of light falling on the cell cathode increases, so the conductivity increases. The consequent rise in voltage across R_4 is passed on to the control grid of the charging pentode V_3 in the time base circuit, *via* R_5.

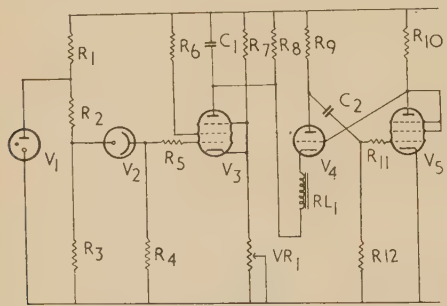


Fig. 2. The control unit

R_1 = 7 kΩ, 1 W
R_2 = 15 kΩ
R_3 = 60 kΩ
R_4 = 3 MΩ
R_5 = 3 MΩ
R_6 = 3 kΩ
R_7 = 25 kΩ, 3 W
R_8 = 1·5 MΩ
R_9 = 5 kΩ, 1 W
R_{10} = 50 kΩ, 1 W
R_{11} = 1 MΩ
R_{12} = 1 MΩ

VR_1 = 1 kΩ

C_1 = 8 mF
C_2 = 0·04 mF

V_1 = OA2
V_2 = 2OCV (photocell)
V_3 = EF91
V_4 = P41
V_5 = EF91

RL_1 = P.O. type 3000 relay, 2000 Ω coil

The frequency of the time base will be determined by the rate of charge of the condenser C_1, and is therefore proportional to the capacity of C_1 and the resistance of the charging pentode V_3. As this is governed by the potentials on the control and suppressor grids, for any given setting of VR_1 the rate of charge of C_1, and consequently the frequency with which the relay switch, RL_1, closes, will depend on the output voltage from the photocell unit. The resistance VR is pre-set to adjust the standing frequency of the time base. Each relay, on closing, also switches on a small neon bulb and so gives a visual indication of the relative amount of light falling on the photocells. A separate heater winding is used to supply the triode V_4, because of the fluctuating potential of the cathode.

THE CATHODE FOLLOWER AMPLIFIER (4)

Since a high degree of linearity between input voltage and output current is required, the circuit shown in Fig. 3 ha been adopted.$^{(8)}$ It is also desirable that the cathode curren shall be as small as possible for zero input voltage. By using an EL84 pentode valve and limiting the maximu cathode current to 30 mA by giving R_k a value of 2170 Ω the cathode current at zero input voltage is less than 4 mA.

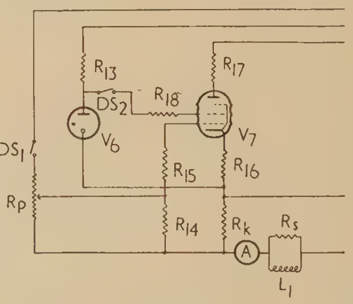


Fig. 3. The cathode follower d.c. amplifier

R_{13} = 15 kΩ, 2 W
R_{14} = 1 MΩ
R_{15} = 250 kΩ
R_{16} = 100 Ω
R_{17} = 100 Ω
R_{18} = 1 kΩ
R_s, R_k, R_p } see text

V_6 = OA2
V_7 = EL84

L_1 = balance solenoid

A = 0–30 mA d.c.

DS_1, DS_3 = delay relay switches

The balance solenoid coil L_1 (resistance approximate 750 Ω), is shunted by R_s, a high stability resistance of abou 15 Ω. An anode potential of 300 V is supplied to V_7, while th screen grid is maintained at 150 V relative to the cathode by stabilizer valve type OA2. This necessitates a separate pow supply for the screen grid. Stopper resistances have bee incorporated in all the valve connections to eliminate hig frequency oscillations. The heater current is supplied by separate transformer winding because of the large variation in cathode potential. A delay relay is included in the anod supply circuit to ensure that the h.t. supplies to the scree grid and to the potentiometer coil are not applied until t anode has reached its operating voltage.

DAMPING

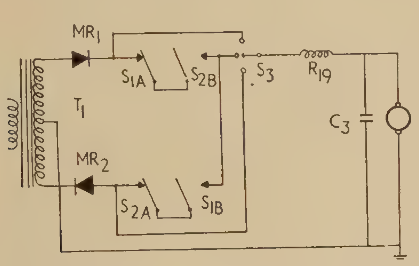
With the present apparatus, as with that of Gregg an Wintle,$^{(6)}$ some provision for damping must be made, otherwise "hunting" is found to occur. It has, howeve been found possible to dispense with electronic methods damping, and thereby to introduce considerable simplification. It is now only necessary that the balance solenoid co shall be of very high inductance, and shall be shunted with resistance. In practice L_1 consists of a winding of 4 in. rnal diameter of 30 s.w.g. enamel covered wire, wound resistance of approximately 750 Ω, thus providing many e turns per inch than are necessary to produce the mag- c field used in the manual control of the balance.[(9)] For shunt, a high stability resistance R_s of about 15 Ω is loyed. Movement of the magnet induces a potential oss the coil, causing current to flow through the virtual t circuit created by the shunt, the induced field being 1 as to oppose further motion. The sensitivity of the nce is not in any way affected, as the damping current is portional to the rate of movement of the magnet.

POWER SUPPLY UNIT

he power supply unit is of conventional design, and utilizes e separate mains transformers, providing high tension plies of 350 V, 70 mA and 250 V, 60 mA for the d.c. plifier, and a common supply of 250 V, 80 mA for the trol unit and potentiometer coil.

THE RECORDING DESK

he diagram of the switching and motor circuits is shown Fig. 4. As either relay switch operates, it connects for a f interval a 12 V d.c. supply of corresponding polarity reversible low inertia motor, and disconnects the opposing uit. A three-way switch has been arranged so that the or can also be operated manually.



ig. 4. Switching and power supply circuits for the potentiometer motor

r_1 = 12 V–0–12 V . 2 A

MR_1, MR_2 = 12 V, ½ A rectifiers

S_1, S_2 = control unit relay switches

S_3 = manual control switch

C_3 = 4 mF

R_{19} = 9Ω

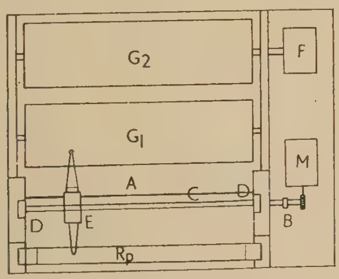


Fig. 5. The recording desk

, guide rod for carriage; *B*, insulated connecting bush; , threaded brass rod; *D*, insulated ball races; *E*, carriage, earing the potentiometer wiper and recording pen; *F*, syn- ronous block motor; G_1, G_2, recording drums; *M*, potentiometer motor; R_p, potentiometer resistance coil.

he recording unit (Fig. 5) is constructed on a wooden board 18 × 12 in. The potentiometer motor *M* is connected, via 16/1 reduction gearing, by an insulated bush *B* to a 5/16 in. B.S.F. threaded rod *C*, which is supported at either end by insulated ball races *D*. A carriage *E*, operated by rotation of the threaded rod, carries a wiper resting on the potentiometer coil R_p, connection to the amplifier being made through the guide rod *A*. Safety switches (not shown in Fig. 4) mounted at either end of the threaded rod automatically disconnect the potentiometer motor when the carriage reaches the limit of its traverse. The potentiometer is wound to a resistance of 17 kΩ with 44 s.w.g. enamel covered wire, on a 1 in. diameter Paxolin former. A stabilized potential of 75 V is maintained across it by a Mullard type 75 B1 valve. The carriage *E* also carries an insulated pen which traces its position on the graph paper. The synchronous clock motor *F* drives the recording drum G_2 at a rate of 1 rev/h causing the graph paper to be transferred from drum G_1 to drum G_2 at about 10 in./h.

CONSTRUCTION

The whole equipment, with the exception of the recording desk, is constructed on a chassis 12 × 16 × 2 in. deep. The recording desk is connected to the chassis by a multicore cable, and carries the three-way switch together with switches for the drum and potentiometer motors.

Only standard radio and electrical components of current design have been used, and the electric motors are types available commercially. Particular care has to be taken in the construction of the threaded rod driving the potentiometer carriage, otherwise the jerky motion of the pen would become discernible on the graph.

In order to increase the range of the balance, a magnet has been placed on the bucket side of the balance arm. This is surrounded by a second solenoid, through which current may be passed (from an accumulator) to oppose the pull of the first solenoid. Each time the pen reaches the edge of the graph paper an increment of current equivalent to 220 mg is passed through the solenoid, so restoring the pen to its initial position.

CALIBRATION AND OPERATION

The apparatus is calibrated by direct addition of small weights to the balance bucket, and the pen displacement on the graph per milligramme load is recorded. In the present model the relation between displacement of the pen on the paper and load added is linear to ±0·75%. To calibrate the second solenoid the balance is first set in its null position with the pen near the centre of the graph; successive small weights are then added and the current required to restore the pen to its original position is determined potentiometrically. The current/weight relationship is again found to be linear. The rate of return of the balance to its null position may be varied by adjusting the series rheostat in the lamp circuit, once the standing frequency of the time bases has been set.

The method of operation is best explained by quoting a definite case, viz. a thermal decomposition. The balance carrying the sample is first set at the "heavy" end of the graph by lead counterweights, with a water cooled metal coil surrounding the counterweights and upper part of the balance limb. As loss in weight occurs, the pen moves across the graph, finally reaching the edge of the paper. The pen is then returned to the "heavy" end of the scale by means of the key switch (the projector light being switched off meanwhile) and the current in the second coil is rapidly adjusted. This process may be repeated several times, i.e. until the limit of the apparatus has been reached (say 5 g). A typical graph so obtained is shown in Fig. 6.

APPLICATIONS

The apparatus is capable of following changes in weight of a sample when exposed to vacuum, or to a given gas, at temperatures of up to 1000° C. Initial experiments carried out in these laboratories have shown it to be suitable for studying thermal decompositions, sorption of vapours by solids, gas-solid reactions, and thermogravimetric analysis, both in air and in vacuum. A curve obtained for the isothermal dehydration of titanium dioxide under vacuum is shown in Fig. 6. The use of the apparatus for thermal gravimetric analysis is illustrated in Fig. 7, by the thermal decomposition curve for magnesium oxalate dihydrate, at a rate of rise of temperature of 300° C per hour. The reaction was found to follow the same course as that observed by Duval,(10) i.e.

$$\begin{array}{ccccc} Mg(CO_2)_2 2H_2O & \longrightarrow & Mg(CO_2)_2 & \longrightarrow & MgO \\ 148 & & 112 & & 40 \end{array}$$

A number of sorption isotherms of butane gas on ground graphite at 0° C have also been determined, giving a very clear indication of equilibrium times and rates of sorption at various relative vapour pressures. The apparatus showed excellent stability over a period of several days' continuous operation.

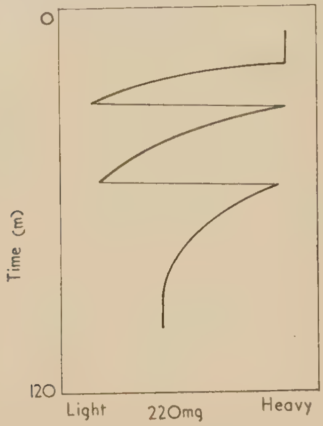


Fig. 6. Dehydration curve obtained for hydrous titanium dioxide under vacuum at 80° C

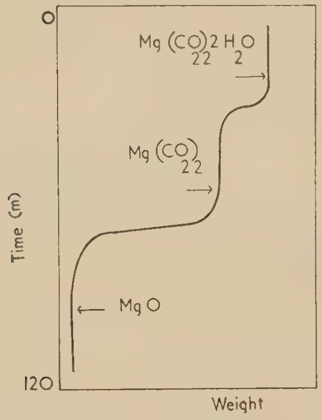


Fig. 7. Thermogravimetric analysis of magnesium oxalate dihydrate, at 5° C/min rate of rise of temperature

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My thanks are offered to Dr. S. J. Gregg for much useful discussion and encouragement throughout the course of this work. Part of the cost of this apparatus was met by a grant from the Royal Society to Dr. S. J. Gregg.

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ptical and instrumental limitations to the accuracy of "oximetry"

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An "oximeter," intended primarily for measuring colorimetrically the oxygenation of circulating blood in living tissues, has been tested on blood contained in glass absorption cells. The instrument reading is shown to depend not only on oxygenation but also on the total amount of pigment (haemoglobin) in the light path, and thus a single calibration curve is only acceptable if this amount is constant. Comparison of the optical density of whole blood with a sample in which the haemoglobin has been released from the corpuscles into homogeneous solution reveals the large contribution to the total light extinction which derives from scattering effects in whole blood. This factor, together with instrumental deficiencies, limits severely the accuracy of measurements with this type of oximeter on blood within the circulation, and the accuracy of the method on whole blood in glass absorption cells is estimated as ±8% oxygen saturation.

1. INTRODUCTION

"oximeter"$^{(1-5)}$ is a miniature filter photometer designed measure the percentage saturation with oxygen of the gment haemoglobin in blood by comparing the light transssion in two separate spectral regions. One waveband, in near infra-red region, is chosen where the light transssion is ideally independent of oxygenation and determined ly by the total haemoglobin in the light path, while the her waveband used is in the red region where the light nsmission is markedly different for the oxygenated and luced forms of the pigment. The ultimate object of imetry is to make these measurements on blood circulating the living subject by transilluminating some conveniently cessible part of the body such as the lobe of the ear or the b of the finger.

Many of the physical factors which govern the accuracy the method can be studied by investigating blood samples closed in glass cells of dimensions approximating to the sue volumes observable in the living subject, and the esent paper describes such an investigation, using a comrcial oximeter based on the design of Stott.$^{(4)}$ This instrunt is a single-scale device in which the difference in output two photocells, sensitive to red (around 650 mμ) and ra-red (around 820 mμ) wavelengths respectively, is corded, after amplification, by a microammeter which rries a scale marked directly in "percentage saturation" of haemoglobin. Our conclusions apply equally to other gle-scale oximeters$^{(3, 5)}$ which have also been described in s *Journal.*

2. OPTICS

2.1 *Absorption of light by haemoglobin.* Assuming the uger–Lambert law of absorption to apply to the optical haviour, in whole blood, of both oxygenated and reduced emoglobin, individually and also that Beer's law holds for xtures of the pigments, then at wavelength λ where the sorptions of HbO_2 and Hb differ we have

$$I = I_0 \times 10^{-(\alpha_1 c_1 + \alpha_2 c_2)d}$$

ere I is the intensity of light transmitted (at wavelength λ), the intensity of the source, d the optical path length, α_1 (α_2) absorption coefficient at wavelength λ of HbO_2 (Hb) at ncentration $c_1(c_2)$.

Similarly at wavelength λ', chosen for equal absorption efficient (α_3) of reduced or oxygenated haemoglobin, we ve

$$I' = I'_0 \times 10^{-\alpha_3 Cd}$$

where C is the total haemoglobin concentration, i.e. $C = c_1 + c_2$.

These equations may now be manipulated in various ways to express the measured quantities in terms of the oxygenation of the blood; for example, if I_0 is made equal to I'_0 we may write, where $S = c_1/C$

$$\log I' - \log I = [S(\alpha_1 - \alpha_2) + (\alpha_2 - \alpha_3)]Cd$$

then S is linear in $\log I'/I$ *for constant* Cd and the gradient of this line varies with Cd:

$$d/dS\,(\log I' - \log I) = (\alpha_1 - \alpha_2)Cd \qquad (1)$$

In particular, for 100% saturated blood, $S = 1$, and $\log I' - \log I = (\alpha_1 - \alpha_3)Cd$, and for fully reduced blood, $S = 0$, then $\log I' - \log I = (\alpha_2 - \alpha_3)Cd$. These are the limiting values for each of a family of curves for different values of Cd [Fig. 1(*a*)].

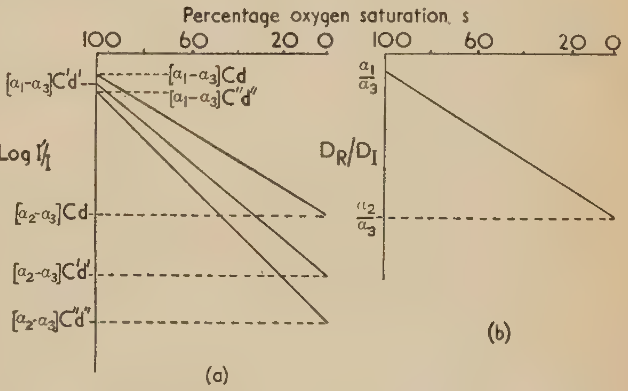


Fig. 1. Two functions useful in determining blood oxygen saturation photometrically

Alternatively, taking into account the incident intensities I_0, I'_0 (which need not necessarily be equal) and writing $\log I_0/I$, ($\log I'_0/I'$) as D_R, (D_I), the optical densities in these wavebands, we have

$$D_R = (\alpha_1 c_1 + \alpha_2 c_2)d$$
$$D_I = \alpha_3 Cd$$

Thus, since $C = c_1 + c_2$ and $S = c_1/C$

$$D_R/D_I = [(\alpha_1 - \alpha_2)/\alpha_3]\,S + (\alpha_2/\alpha_3) \qquad (2)$$

D_R/D_I is thus independent of both C and d, is linear in S and of constant gradient $(\alpha_1 - \alpha_2)/\alpha_3$ [Fig. 1(*b*)]. The limiting values α_1/α_3 for $S = 1$ and α_2/α_3 for $S = 0$ are useful functions with which to check the optical behaviour of whole blood since complete oxygenation and reduction of haemoglobin is easily produced.

2.2 *Scattering of light in whole blood.* The relations derived above apply directly only to a mixture of the pigments in simple solution and may therefore be expected to hold for haemolyzed blood (that is, blood in which the individual cell walls have been ruptured and the blood pigments are in solution in the plasma), as will be illustrated in the experimental results later. However, in whole blood the haemoglobin is enclosed in discoid corpuscles of average diameter about 7 μ and thickness about 2 μ, which make up some 45% of the total mass of the blood. The optical difference between a haemoglobin solution and natural blood is easily appreciated by attempting to read newsprint through a layer of blood before and after rupture of the cell membranes, a blood layer which initially is virtually opaque becoming quite transparent after haemolysis. The considerable quantitative evidence which is available from spectrophotometric studies using conventional apparatus(6–9) indicates that the light scattering in the presence of intact corpuscles is considerable and a far from simple phenomenon. The many variables involved can only be successfully handled by a corresponding complexity in experimental technique.(17)

In what is probably the most reliable spectrophotometric procedure, that of Drabkin and Schmidt,(10) measurements at four carefully selected wavelengths are employed; and even then, whenever possible, they prefer to haemolyze the blood samples first. (Further, these measurements are made at rather short wavelengths where scattering effects become less important compared with true absorption, but the blood-filled ear is too opaque in these shorter wavelengths to take advantage of this.)

In an oximeter only two filtered bands of wavelengths are used. These are insufficient, both in number and in wavelength selectivity, to enable the operation of such instruments to be based on anything but an empirical foundation, so that it is necessary to test whether the optical properties of whole blood can permit the display of an accurate result by a simple single-scale instrument.

2.3 *Photocell and amplifier response.* It is also necessary to ascertain what any particular instrument is in fact measuring. Because of space and weight limitations, particularly when attempting the transillumination of living tissues such as the ear lobe, the light detectors chosen have been, with rare exceptions, selenium barrier-layer photocells. Except when used as null detectors, these are among the most unsuitable devices for the accurate quantitative measurement of light. When used with due precaution they are useful tools, but their response to varying light intensities is a function of the impedance of the load into which the cell works and the absolute level of the light intensity. Under certain conditions with a low load impedance the response is approximately linear, becoming at high load impedance approximately logarithmic.

One assumption in Ref. 3 which would facilitate single-scale operation is that the photocells used respond logarithmically to light intensity variation at the light levels used and that the amplifier response is linear. (Alternatively, that the overall response, amplifier plus photocells, is logarithmic.)

In the instrument used for this investigation, the amplifier proved not to be linear near zero output and was therefore independently calibrated. This done, it was possible to determine the photocell response when working into this amplifier, by interposing different "neutral" filters of known optical density between the light source and the photocells. It was found that under these conditions the barrier-layer cells had not a logarithmic but an approximately linear response to light intensity. Having now determined the overall response to light intensity variation it was possible to test the optical behaviour of whole blood in glass absorption cells, under the precise conditions of observation used in oximetry, by determination of the functions discussed in Section 2.1.

3. EXPERIMENTAL

Blood was equilibrated with gas mixtures for one hour at 37° C in closed vessels. Samples were then withdrawn into syringes, using strict precautions to avoid exposure to the air. Aliquots from the syringes were taken for gasometric determinations of oxygen content by the method of van Slyke and Neil(11) and for measurement of optical density.

The optical measurements were made with the blood stationary in parallel-sided glass absorption cells in the shape of shallow cylinders of about 20 mm diameter and internal depths of 0·76 and 0·35 mm respectively. The cells were fixed in plastic mounts so that they could be repeatably located between the light source and detectors in the "ear-piece" of the oximeter. This arrangement was shown to exclude stray light by filling the cells with Indian ink, when the output from each photocell fell to zero.

Before introducing a blood sample, the absorption cell was filled with isotonic saline and the outputs of the red and infra-red sensitive photocells balanced. After introduction of the blood the cell outputs reached new steady values in about ten seconds, and these values were maintained for about ten minutes. The overall calibration of the instrument was applied to convert these readings to D_R and D_I values.

4. RESULTS

Fig. 2 shows values of D_R/D_I for haemolyzed blood samples and whole blood, measured with the calibrated instrument. The curve for haemolyzed blood fits equation (2) well with reasonable values inserted for α_1, α_2, α_3. For whole blood D_R/D_I becomes much less sensitive to percentage saturation changes. Grossly the curve *AA* would be followed if there were added to the optical behaviour of haemolyzed blood an isotropic scattering of coefficient β such that

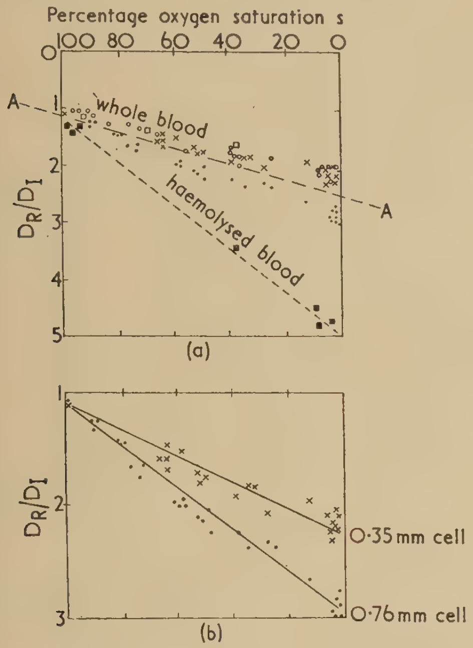
$$\beta \text{ red light} = 6{\cdot}5\,\alpha_3$$
$$\beta' \text{ infra-red light} = 4{\cdot}3\,\alpha_3$$

Thus, even roughly, the scattering effect is four or five times the true absorption in the infra-red region.

In more detail, however, the agreement for two cell-depths is not good [Fig. 2(*b*) as Fig. 2(*a*) but with expanded ordinate scale], although it will be seen that for any one calibrated absorption cell a single measurement of *S* can be made to about ±8% oxygen saturation, and there may be some point in using the instrument this way when time is at a premium and greater accuracy of little account. There is, however, no doubt that a unique scattering coefficient for whole blood independent of the conditions of observation is a wholly inadequate assumption. The reasons are to be found both in the magnitude and the complexity of the scattering of light by whole blood.

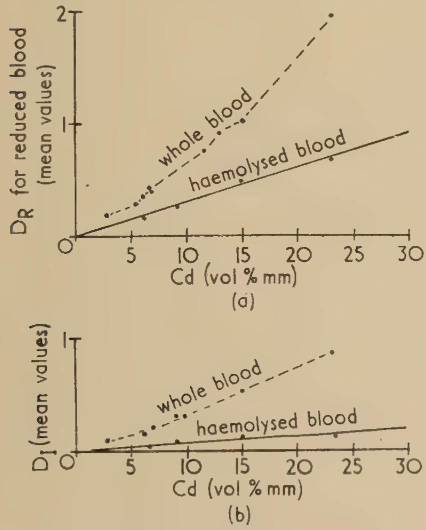
Fig. 3 showing mean values of D_R, D_I separately for whole and haemolyzed blood is included to underline the difference in optical behaviour between whole and haemolyzed blood and to show the individual optical densities measured in the arate relevant red and infra-red wavebands under these ditions of observation.

he mean value curves of Fig. 3 are reasonably well ned. However, single observations of D_I (for example) w considerable instrumental scatter and a measurement of alone is not sufficiently accurate for use in determining the l haemoglobin.



ig. 2. Measurement of D_R/D_I for whole and haemolyzed blood with a calibrated oximeter

ell depths: ○ = 1·13 mm. ● = 0·76 mm. □ = 0·45 mm. × = 0·35 mm. ■ = haemolyzed blood (mean values).



ig. 3. Optical densities of whole and haemolyzed blood as measured by a calibrated oximeter

5. DISCUSSION

he effects of light scattering by the corpuscles as evidenced the divergence between the transmission for whole blood for an equal haemoglobin concentration in simple ition when the blood is haemolyzed (Figs. 2, 3) have been reported upon by Evans(7) and more recently by Lothian and Lewis.(12) The work described by Evans stemmed from some investigations by Mendelssohn and Evans at the Clarendon Laboratory which, while providing some justification for attempting oximetry on an empirical basis, also called attention to the importance of the geometry of the instrument when attempting absorption measurements on a turbid medium, particularly when scattering effects are as large as or larger than true absorption. With a well collimated monochromatic beam of light, narrow compared with the depth of the absorption cell, and with a very restricted angle of acceptance for the light detector, Evans showed that the scattering can approach reliable theoretical prediction. In the oximeter, the receiving area is a rectangle of about 0·8 cm^2, each photocell occupying about one-half of this area, and the depth of blood is only 0·76 or 0·35 mm compared with the diameter, about 10 mm, of the far from monochromatic light beam. A large fraction of the light received has been scattered out of the direction of the incident beam, but is unpredictable in amount, and is likely to vary considerably from one earpiece to another.

If all the scattered light can be collected it can be shown that, if the ratio of true absorption to scattering is not unduly low, then it is possible again to achieve predictable total extinction.(12) These conditions cannot hold in a conventional oximeter for advantage cannot be taken of regions of higher true absorption coefficient, since blood depths in accessible tissues are such that the total attenuation of the light becomes too great. Lothian and Lewis confirm the magnitude of this effect at the wavelengths used here. Experiments of our own, using a ground glass absorption cell and diffuse light show that these merely serve to reduce the relatively small difference in extinction exhibited between stationary and flowing blood in the oximeter method.

Our observations thus indicate that the use of a single-scale oximeter on blood samples contained in glass absorption cells involves too many variables to permit a direct reading of oxygen saturation at different blood depths or at different total haemoglobin concentrations, since the instrument investigated gave readings on the “saturation” scale which were markedly dependent upon C and d. Even assuming a correctly logarithmic overall response to light intensity, this result would be predicted from equation (1). The equation (Ref. 3) upon which the design of the instrument is based appears invalid. However, by detailed calibration of an individual instrument so as to permit the calculation of D_R and D_I it is possible to determine the oxygen saturation of whole blood to ±8%. This may be useful if the speed of performing such an assay is of prime importance or when the object of an experiment is to display gross changes happening quickly. Thus, the glass absorption cell may, in an animal experiment, be inserted directly into the course of the circulation by placing it between the ends of a divided blood vessel, or, in a human experiment, it may be attached to a catheter or needle through which blood may be drawn from an artery, vein or chamber of the heart. However, when there is no special advantage in retaining the blood in an unhaemolyzed condition it is preferable to liberate the haemoglobin into homogeneous solution. This done, the oximeter has no special advantage over conventional spectrophotometric apparatus and the precise instrument used can largely be governed by the accuracy desired.(10, 13, 14) If, however, an “earpiece” method is essential, then there is much to be said for following the American practice(2) of working the photocells directly into a galvanometer. This avoids the instrumental difficulties inherent in operating these detectors into conventional valve amplifiers; it also permits a better monitoring of the constancy of their characteristics and allows a more direct calculation of D_R and D_I.

Stott(15) has commented that, because of both physiological and instrumental difficulties, oximeters are never likely to achieve high accuracy, and even if a limited success is hoped for it is essential that the response of individual photocells in each earpiece is known. An adequate light intensity is essential, since at low light levels the response of barrier layer cells varies considerably. The main use of the oximeter would appear to be in fully controlled experiments in which the instrument can continuously record changes and also be checked from time to time.

As regards the use of the oximeter on the ear of living subjects, our own experience has been discouraging in that there has been poor agreement between the readings from the oximeter and gasometric estimations of the arterial blood oxygenation. In general, the oximeter in our hands has correctly signalled the direction of changes but only poorly estimated their magnitude. This standard of performance may be sufficient for certain practical purposes, such as monitoring patients or checking the constancy of experimental conditions in physiological studies. It may be observed here that the technique of reflexion oximetry(16) offers no solution; a significant part of the reflected light comes from layers at depths of the order of a millimetre below the surface of the blood and suffers, therefore, all the complex attenuations discussed above during its double transmission through that thickness of blood.

ACKNOWLEDGEMENTS

We are indebted to Mr. J. L. M. Hole, of Stanley Cox, Ltd., for placing at our disposal a "Stanco" oximeter; to Dr. F. D. Stott for the loan of the prototype instrument; to Mr. D. Saxton for the construction of the parallel-sided glass absorption cells used; to Miss Ann Sweeny, for help wit some of the measurements and to Dr. K. A. G. Mendelssohn for discussion of this paper.

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A solid state paramagnetic resonance spectrometer

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A spectrometer is described for use in the frequency range 9000 to 10 000 Mc/s and at the fixed temperatures of boiling refrigerants and a small range below obtained by pumping on the liquid. The lowest temperature available is the triple point of hydrogen (14°K). A high sensitivity is achieved by modulating the magnetic field at 115 kc/s. The sensitivity is such that 10^{13} atoms of ^{56}Co have been detected at 20°K with a signal/noise ratio of 3 : 1; it is estimated that 2×10^{-11} moles of the free radical diphenyltrinitro phenyl hydrazyl (DPPH) would be detectable at 290°K.

INTRODUCTION

The investigation of paramagnetic resonance in the solid state has now expanded to cover problems in many fields. In spite of this the requirements of a paramagnetic resonance spectrometer are fairly standard. The sample is usually small, for instance a single crystal of $0{\cdot}1$ cm^3 or less, which is placed in a resonant cavity in a homogeneous static magnetic field. At resonance, absorption of the microwaves takes place which can be detected in a number of ways. A simple and at the same time fairly sensitive spectrometer is discusse by Bleaney and Stevens(1) where references to other instruments can be found. In this paper a development of th spectrometer is described which is both very sensitive and a the same time has the merits of simplicity and flexibilit The spectrometer operates in the range 9000 to 10 000 Mc and is of the transmission type with a silicon-tungsten rectifie as the detecting element. These rectifiers have an exces noise at low frequencies whose power varies inversely wit the frequency. Hence a major improvement in the sensitivit can be obtained by using a system where amplification of th rectifier output is made at a high frequency. This is effecte modulating the external magnetic field at 115 kc/s instead the usual low frequency of *ca.* 50 c/s. The gain in sensitivity ounts to a reduction by a factor of 30 in the number of gnetic centres required to give a signal equal to the noise. gh frequency field modulation has been used also by ckmaster and Scovil(2) for low temperature work at 25 cm wavelength and by Bowers, Kamper and Knight(3) resonance work with gases and free atoms.

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MODULATION OF THE MAGNETIC FIELD AT 115 KC/S

The frequency of 115 kc/s was chosen as convenient cause components for this frequency are readily available. ie system described below gives modulation amplitudes up 20 G peak to peak of the field in the region of the sample ing an oscillator of about 15 W output. Three cavity signs have been used, the third being much superior to other two; these will now be briefly described.

First, a 3 cm wavelength H_{101} resonant cavity of a design nilar to that described by Bleaney and Stevens(1) was odified as follows. A coaxial line was taken through the ttom of the cavity and terminated by a loop which is just side the cavity.(4) The orientation of the loop is variable. current of a few amps at 115 kc/s is fed into the loop side which is placed the paramagnetic sample. The presence the loop does not disturb the cavity as long as the plane the loop is parallel to the microwave magnetic field in the vity. This gives a modulating field perpendicular to the crowave magnetic field, the condition normally required. is loop system has the disadvantages: (1) lines for which microwave and magnetic fields need to be parallel cannot observed; (2) it is difficult to orient single crystals inside loop.

In the other designs a modulating coil is placed outside the vity close to its top. Originally a 1 cm diameter hole was de in the top of the H_{101} cavity and the sample placed on quartz plate across the hole. Although the diameter of the le is beyond cut-off for the microwaves a certain amount coupling to the modulating coil takes place and the sultant microphonic effects from movements of the coil are ticeable. A loss in sensitivity also results from the preading" of the microwave magnetic field in the region of hole which gives a poorer filling factor. These troubles re overcome in the final design for the modulation of the ld at 115 kc/s shown in Fig. 1.

In this final design a thin sheet of metal, originally copper, s soldered across the hole to complete the cavity. The ckness of the sheet was chosen to be intermediate between skin depth for 10 000 Mc/s and 115 kc/s, thus closing the vity for microwaves but still allowing the 115 kc/s magnetic ld to penetrate into the cavity. The cavity was designed to used at temperatures from 290° K to 14° K and the above terion cannot be satisfied in the whole range of temperature eded. Because of this an alloy, German silver, was finally osen which has an almost constant resistance down to K. This cavity design proved satisfactory in every way en used with 115 kc/s modulation. In an experiment the ramagnetic crystal is thus always placed at the top of the vity and the modulating coil oriented to the correct ection before the cavity is cooled to low temperatures. e paramagnetic sample is fixed in the correct orientation the top of the cavity with a small amount of rubber grease. order to prevent the sample from moving at low temperaes, when the grease freezes, the cavity is filled with a block polystyrene foam.

The same cavity design has been used with 465 kc/s modulation. In this case, however, eddy currents in the walls of the cavity limited the amount of magnetic sweep available and the crystal could not be kept at a low temperature with sweep amplitudes of greater than a few gauss peak to peak. Although the noise figure of the system is considerably better than with 115 kc/s modulation little or no gain in sensitivity was achieved.

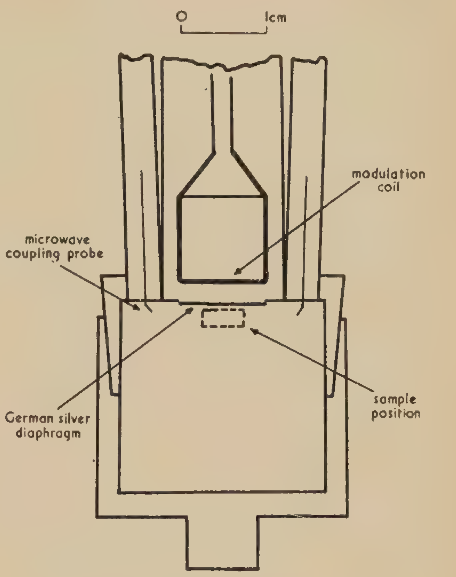

Fig. 1. Resonant cavity detail

THE SPECTROMETER

The resonant cavity assembly. The important leads and components of the resonant cavity assembly are marked on the block diagram of the spectrometer in Fig. 2. The resonant cavity itself is of brass, split at its mid-point where there are no microwave currents flowing; the supports of the cavity are of German silver tubing, which has a low thermal conductivity. In an experiment at low temperatures the cavity, leads and tube containing the 115 kc/s modulating coil are filled with helium gas, while the cavity and stem are immersed in refrigerant contained in a dewar flask of internal diameter 2·8 cm and external diameter 4·0 cm. With liquid hydrogen the cavity can be kept at 20° K for $\frac{1}{2}$–1 h without refilling, and by pumping the space over the liquid hydrogen the temperature can be lowered to 14° K. The proton resonance head and coil for field measurement also form part of the assembly; the proton coil is close to the top of the resonant cavity.

The detection of paramagnetic resonance. The method of detection and display of the paramagnetic resonance absorption signal depends on its strength. For strong signals (10^{15} magnetic centres and over), a magnetic sweep at 115 kc/s of half the line width is applied and the field swept over a range larger than the line width at 50 c/s; for weak signals the field is swept slowly through resonance and a narrow bandwidth is employed. Greater resolution but a corresponding loss in sensitivity is obtained with a smaller 115 kc/s sweep amplitude. Fig. 2 shows the detection system in block diagram form. The microwaves are rectified by the conventional silicon–tungsten rectifier and the signal fed to a 115 kc/s pre-amplifier, consisting of two stages of amplification with a tuned input. The bandwidth of these stages is about 8 kc/s and the gain is about 10^5 so that the noise amplitude at the output is about 100 mV when microwaves are fed to the rectifier. If the spectrum is being swept at 50 c/s then the 115 kc/s signal will be amplitude modulated at an audio frequency which can be detected by a diode, amplified and fed to an oscilloscope whose time base is synchronized with the magnetic field sweep at 50 c/s. This gives a signal such as that shown in Fig. 3(*a*), the modulus of the differential of the absorption shape. The improvement in signal to noise ratio over low frequency (50 c/s) field modulation can be seen by comparing Fig. 3(*a*) with 3(*b*).

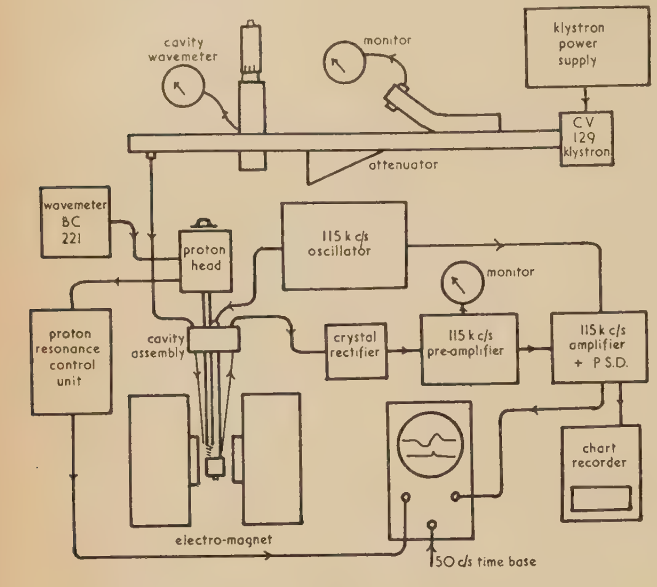

Fig. 2. Block diagram of spectrometer

In order to achieve the greatest sensitivity a phase sensitive detector (P.S.D.) at 115 kc/s is employed. After amplification as above the signal is fed to a phase shift stage which is a one-valve amplifier giving an adjustable phase shift. The signal then undergoes further amplification before being passed to the phase sensitive detection stage. This consists of an electronic switch composed of diodes fed with a switching voltage, the reference signal. The magnitude and sign of the output from this stage depend on the relative phases of the absorption signal and the reference signal. If the bandwidth is large enough (8 kc/s) and the field is swept at 50 c/s the signal from this stage then appears on the oscilloscope as the paramagnetic resonance signal in Fig. 3(*c*).

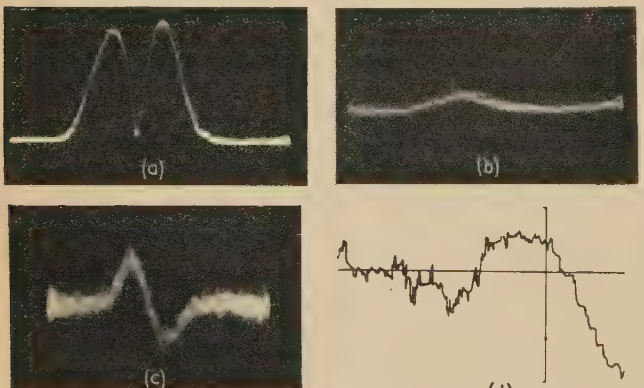

Fig. 3. Paramagnetic resonance absorption signals

(*a*) 10^{16} atoms of ^{59}Co in $ZnK_2(SO_4)_2 . 6H_2O$
$T = 20°$ K, $2\Delta H = 12$ G
(*b*) As 3(*a*) using 115 kc/s field modulation
(*c*) 5×10^{14} atoms of Cu in $ZnK_2(SO_4)_2 . 6D_2O$
$T = 20°$ K, $2\Delta H = 4$ G
(*d*) 10^{13} atoms of ^{56}Co in $ZnK_2(SO_4)_2 . 6D_2O$
$T = 20°$ K, $2\Delta H = 6$ G

A further gain in sensitivity of the order of 100 is obtained when the bandwidth is reduced to 1 c/s following the phase sensitive detector; this requires a slow traverse of the magnetic field over the absorption line, which is charted on a recording milliammeter. The signal from 10^{13} atoms of ^{56}Co obtained in this way, with a bandwidth of 1 c/s in the system, is shown in Fig. 3(*d*). (The asymmetry of the line arises from the proximity of a line of greater intensity from the stable isotope ^{59}Co.) In attaining the ultimate sensitivity the biggest problem is interference from unwanted signals of the modulation frequency. These are eliminated by careful screening of the leads and components carrying the 115 kc/s modulation current and of the stages of the preamplifier. The avoidance of "earth loops" is essential.

The magnetic field. The magnetic field is produced by an electromagnet by Tickfords Ltd. and in common use in the Clarendon Laboratory. For X-band work this has pole faces of 10 cm diameter. The main exciting coils produce a field of up to 7 kG in a 4·2 cm gap. With the aid of Rose's rims⁽⁵⁾ the homogeneity in the centre of the gap is better than $\frac{1}{2}$ G over a volume of $\frac{1}{2}$ cm^3. The magnet can be rotated through 360° about the vertical axis and the angle measured on a fixed scale to 10′ of arc. In order to use the narrow bandwidth and ultimate sensitivity mentioned above, the absorption line must be swept through in field in a time long compared with the time constant of the phase sensitive detection stages. For this purpose a simple and inexpensive field stabilization scheme is used. The voltage across the main exciting coils is held constant by floating a bank of accumulators across the coils.⁽⁶⁾ The magnet is fed from a source of reasonably high impedance (20 Ω) compared with the internal resistance of the accumulators. It is found using this system that after a warming period of 1–2 h the drift in the field is less than 20 G an hour and the "jitter" less than 1/10 G. This performance is quite sufficient for all solid state work where few lines are less than 4 G wide and the time to sweep through a line need rarely be more than a minute. The spectrum is traversed by varying the current through a pair of auxiliary coils giving an additional field of up to 500 G.

The measurement of field and frequency. The magnetic field is measured by the detection of proton magnetic resonance, using a regenerative circuit, in the same field as the paramagnetic resonance. The frequency of proton resonance, normally between 4 and 30 Mc/s, is measured by a BC 221 wavemeter. For experiments at liquid hydrogen temperatures the protons of the liquid hydrogen form the sample, at other temperatures a suitable sample is inserted into the proton resonance coil. For strong paramagnetic resonance signals the paramagnetic and nuclear absorption signals are fed to the two beams of a double beam oscilloscope and the proton resonance adjusted to be coincident with the paramagnetic resonance absorption. This setting is shown in Fig. 4. Owing to eddy currents, the phase of the sweep is slightly different at the paramagnetic and proton samples, and gives rise to the displacement of the forward and return signals from the protons.

he microwave frequency, the source of which is a CV 129 ex klystron, is measured by a cavity wavemeter calibrated inst a frequency standard. It should be added that no uency stabilization of the CV 129 is necessary, when using power supply designed by Mr. L. J. Arundel of the rendon Laboratory.

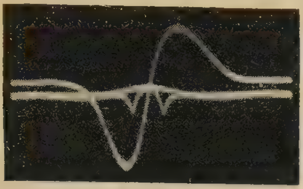

Fig. 4. Proton resonance setting

PERFORMANCE

he spectrometer was tested to its limit of sensitivity in the eriments(7) performed to determine the nuclear spin and gnetic moment of ^{56}Co. These experiments provided a venient sensitivity check since the number of ^{56}Co atoms known from the activity. Fig. 3 shows the signals from ious specimens. ΔH gives the half width of the absorption at half intensity in gauss. Fig. 3(*c*) shows that 10^{15} atoms easily investigated using a 8 kc/s bandwidth and oscillo- pe display. Fig. 3(*d*) shows the signal from 10^{13} atoms of o at 20° K using a 1 c/s bandwidth. After allowing for erences in g-factor, temperature, line width and multi- ity due to hyperfine structure, this is equivalent to × 10^{-11} moles of the free radical DPPH at room tempera- e or an ultimate sensitivity (for unit signal/noise ratio) of 10^{-11} moles of DPPH. This indicates that the spectro- er is comparable in performance with the calculated sitivity of a system using bolometers(8) and the observed formance of a system using superheterodyne detection.(9) t is of interest to compare the theoretical sensitivity with practical. If the paramagnetic sample is subjected to an llating magnetic field $H_1 \cos \omega t$, the power absorbed by $\frac{1}{2}\omega\chi'' H_1^2$ where χ'' is the imaginary part of the suscepti- ty of the sample. An expression for the theoretical imum value χ''_{min} that can be detected is given by Bleaney Stevens(1):

$$\chi''_{min} = \frac{V}{\pi Q}\left(\frac{NkT\,df}{P_1}\right)^{1/2}$$

effective volume of the cavity at 3 cm wavelength is ut $V = 3$ cm^3, and the value of its quality factor Q about 0. The oscillator power P_1 is about 5 mW (the CV 129 deliver more power than this, but the rectifier current cannot usefully be increased above 0·5 to 1 mA because of the higher noise temperature produced). N is the receiver noise factor, which is the product of the conversion loss in the rectifier and the noise temperature. The former is about 4(6 dB), and from Torrey and Whitmer(10) the noise temperature at 115 kc/s is about 200, so that $N = 80$. Hence we obtain a value for the theoretical χ''_{min} of about 10^{-11}. This is in good agreement with the value of χ'' corresponding to 2×10^{-11} moles of DPPH, which is also about 10^{-11}, but uncertainties in the estimates of the various quantities could easily vary these values by a factor 2.

It can be seen from the above description that this spectrometer is both very sensitive and at the same time simple. It does not need any critical microwave adjustments nor any specific frequency stabilization of the klystron. The added sensitivity is very useful for the investigation of anisotropic spectra using an oscilloscope display. Finally, the paramagnetic resonance absorption signal is completely free from microphonic effects which is in itself a great advantage over the low frequency modulation system.

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An evaporated gold bolometer

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[*Paper received* 22 *November*, 1956]

The construction of a bolometer is described in which the element—of evaporated gold supported by a thin plastic film—is 2·6 mm long, 0·2 mm wide and has a resistance of 15 Ω. In vacuum it has a sensitivity of 1·5 V/W and a minimum detectable energy of $3 \cdot 6 \times 10^{-10}$ W, both measured at 10 c/s. The time constant in vacuum is 7 ms.

There is still a very limited choice of infra-red detectors particularly for wavelengths beyond the sensitivity region of photoconductive cells. The work described here extends the choice by providing a non-selective detector, the performance of which compares favourably with the other detectors of this class. Several papers(1,2,3) have already been published on the theory and construction of bolometers in which the sensitive element has been deposited by the process of vacuum evaporation, but none of these units has been specifically designed for use in an infra-red spectrometer. The sensitive element of the bolometer here described is of evaporated gold supported by a thin plastic film. It is 2·6 mm long, 0·2 mm wide and estimated to be 0·03 μ thick. It has a resistance of about 15 Ω and a change of resistance with temperature of 0·2% per °C, i.e. about half the bulk value.

Initial attempts to produce a high resistance semi-conducting bolometer by evaporation, using tellurium in particular, failed to produce a film sufficiently free from current noise to be useful, and although Gillham(4) has described a bolometer with the sensitive strip of amorphous antimony deposited by sputtering, evaporation has so far failed to produce a stable film of antimony in the amorphous form.

When attention was turned to the metals, tin, copper and silver proved liable to breakdown and noise because of oxidation while nickel and gold immediately looked promising. Gold was chosen of this latter pair because it could readily be evaporated with little danger of damaging the thin plastic supporting film.

CONSTRUCTION

Support and backing film. A support for the bolometer (Fig. 1) 3 cm long and 1 cm wide is cut from sheet mica 0·004 in. thick and out of the middle of this strip is punched a small slot, with rounded ends, 4 mm long and 1·5 mm wide. One side of this support is "greyed" by rubbing it on a fairly fine emery paper and scraped with a razor blade to remove any roughness on the edges of the slot.

The backing for the bolometer is a thin film of cellulose nitrate stretched over the mica support. To make this film 0·5 g of cellulose nitrate is dissolved in 100 ml of amyl acetate and a clean glass slip, about 1·5 cm wide, is dipped into a specimen tube of the solution. The coated slip is withdrawn gently and hung up vertically to drain and dry. Drying takes at least forty-five minutes but the coated slip may be stored for several days. When ready the film can be stripped from the glass by lowering it slowly into distilled water at about 35° C. It is convenient, and it facilitates stripping, to cut the film with a razor blade to the size required (about 8 × 20 mm) while it is still on the glass. Stripping is further eased if the slip is held with the required film side downwards just above the surface of the water for a few seconds until a uniform mist forms over the film and the interference colour becomes visible. The slip is then turned over and gently lowered at a slight angle into the water so that the film floats free. The slip is dropped to the bottom and any unwanted floating portions of film removed. The mica support is now slipped, greyed side uppermost, under the floating film and lifted gently so that the film settles upon it squarely over the slot. Surplus water is drained off with filter paper and the support and film are put into a desiccator to dry.

When dry the film is taut over the slot, showing a pale blue interference colour. It adheres firmly to the mica without the use of an adhesive—the greying assisting this adhesion.

Deposition of electrodes and element. The electrodes are deposited by the vacuum evaporation of gold from a molybdenum boat. The film is masked by placing a strip of copper foil 2·6 mm wide across the support over the middle of the slot, holding it in position with a wire clip. This assembly is supported 8 cm above the boat and gold evaporated upon it until the electrodes show a deep green colour by transmission.

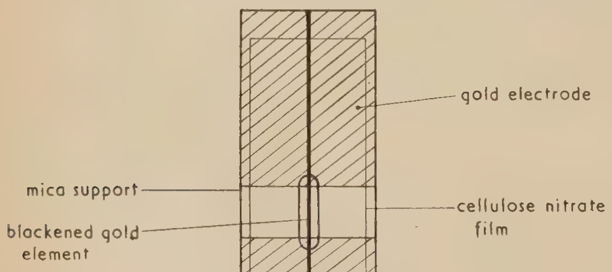

Fig. 1. Diagram of bolometer

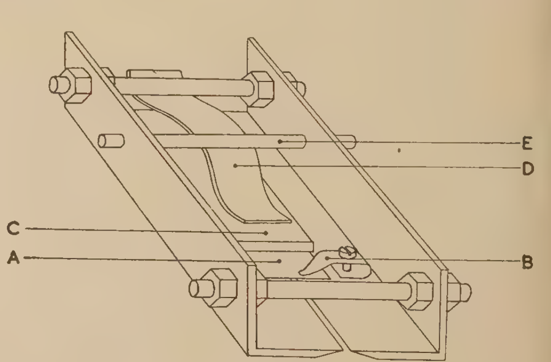

Fig. 2. Mask used for evaporation of the element

The bolometer element is also of evaporated gold and the mask unit for this task is illustrated in Fig. 2. It consists of two pieces of $\frac{3}{8}$ in. brass angle held as shown by two lengths of 0 B.A. studding. The adjacent edges of the angle are chamfered and their separation adjusted with a feeler gauge

·2 mm. The bolometer support *A* is laid in the mask, side down, and positioned so that the slot lies centrally the gap. The position is secured by tightening the clip one end and the rest of the support is covered by a brass king plate *C*. This is fixed by the clip *D* held by rod *E*. he mask is supported 8 cm above a molybdenum dimple t so that the gold strip is deposited through the gap. A th of 1·4 cm of pure gold wire 0·330 mm in diameter is pletely evaporated from the boat.

lacking the strip. The method consists of evaporating l in an atmosphere of an inert gas at a low pressure.(5,6) evaporation is carried out from a filament made by ding a V in the middle of a piece of tungsten wire 1 mm liameter. A length of 7 cm of fine gold wire 0·457 mm iameter is wound round the filament at the V and a bead ned by melting the gold in a vacuum. The bolometer, in the mask unit, is supported 3 cm above this filament. evaporation takes place in an atmosphere of nitrogen at ressure of between 1·75 and 2 mm of mercury. It is ntial to ensure that as little oxygen as possible is present n the nitrogen, otherwise the black transmits a large pro- tion of radiation of wavelength longer than 1 μ. To ieve this the vacuum chamber is evacuated to a hard uum using both backing and diffusion pumps and then the ogen is allowed to flush through the system and the ssure to build up to several centimetres of mercury. This uence is repeated four times, but the last time the pressure educed only to the working value and the chamber sealed The evaporation is accomplished by passing 35 A ough the filament for four minutes.

'or the black to be adequately deposited on the bolometer nent, the chamfer on the sides of the mask must be very llow. Further, it is essential to use a backing plate ind the element to act as a heat sink. The completed ometer is removed from the mask.

TESTING THE BOLOMETER

'or the purposes of testing, the bolometer was mounted de a brass canister with a rocksalt window in the side. whole was sealed with O-rings so that it could be cuated when desired. Fine wires, 36 s.w.g., of tinned per, soldered with indium to the electrodes, were brought through vacuum seals to a plug. Indium was employed he solder because it adhered strongly to the evaporated l and its low melting point enabled it to be used without nage to the film.

Resistance. The resistance of the bolometer was measured g a Wheatstone bridge in which care had been taken to ure that excessive current did not pass through the ometer. Although evaporation conditions had been ndardized there was still found to be a variation in the stance of the order of ±10% of a mean value of 15 Ω. the new bolometer aged the resistance gradually fell. If process was unaided, in the course of several days the stance dropped about 10%, after which there was less n 1% further decrease with time. However, this aging considerably speeded up either by heating the bolometer in oven to about 60° C or by passing a current, such as excitation current, through it. Two hours of such treat- nt was sufficient to age the bolometer and appeared to se no change in bolometer noise.

ensitivity and minimum detectable energy. To make these s the bolometer was placed so that it received radiation n a black body, which consisted of a blackened solid brass nder wound with an electrical heating element which maintained it at a temperature of 450° K measured by a thermometer. A set of apertures controlled the amount of energy reaching the bolometer, this amount being calculated from the physical constants of the arrangement. A rotating sector disk chopped this energy at 10 c/s.

The bolometer circuit (Fig. 3) was suggested by Chasmar.(7) The current to energize the bolometer *B* was provided by accumulator *A* and limited by resistor R_1. A backing-off current through the small resistor R_2 was derived from accumulator *C* and adjusted by R_3 until a current of not more than about 5 μA flowed in the primary of the transformer. The transformer was designed to match an input resistance of 10 Ω to the input of a high gain, narrow band amplifier. This amplifier was tuned to 10 c/s and its output measured on a recording milliammeter. The amplifier had been previously calibrated and measurements were made of the r.m.s. signal and r.m.s. noise from the bolometer.

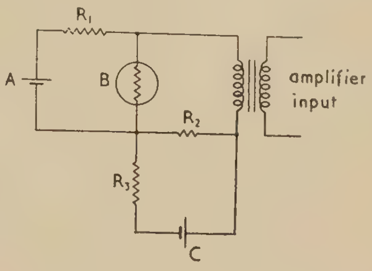

Fig. 3. Circuit of bolometer
$R_1 = 100\,\Omega$ $R_2 = 1\,\Omega$ R_3 is variable

The sensitivity of the bolometer, i.e. the signal produced in volts per watt of incident energy, was measured with the bolometer at atmospheric pressure and in vacuum. The minimum detectable energy, defined as the amount of energy that had to be incident on the bolometer to produce a signal equal to the noise, was determined for the bolometer in vacuum.

Frequency response. Curves showing the relative response of the bolometer in air and vacuum at different frequencies of chopping are shown in Fig. 4. These were obtained by illuminating the bolometer with radiation from a tungsten source modulated sinusoidally. The bolometer was energized as before and coupled by a transformer to a cathode-ray

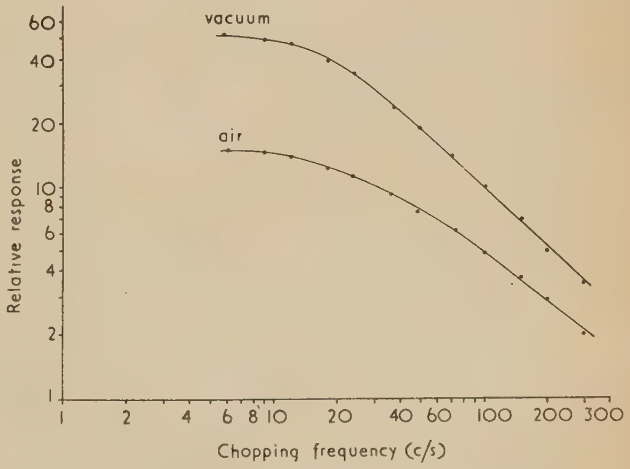

Fig. 4. Frequency response curve of the bolometer in air and vacuum

oscilloscope. Corrections had to be applied for the frequency characteristics of the transformer which worked satisfactorily down to 4 c/s. The chopper was driven by a Velodyne and the frequency determined by using the signal from a tunable oscillator to produce a stationary Lissajous figure.

A different system of amplifying the signal from the bolometer was also tried. In this the bolometer was in one arm of a Wheatstone bridge fed with 1000 c/s alternating current while the output was again taken through a transformer on to the oscilloscope. The signal from the bolometer modulated the 1000 c/s signal appearing on the oscilloscope. This arrangement was independent of the frequency characteristics of the transformer but proved more cumbersome to use than the method described above.

PERFORMANCE

The following results were for a bolometer of resistance 14·8 Ω typical of those produced by the methods described here:

sensitivity in air at atmospheric pressure = 0·43 V/W
sensitivity in vacuum = 1·5 V/W
minimum detectable energy in vacuum = $3 \cdot 6 \times 10^{-10}$ W

These results indicated that the noise was very close to Johnson noise.

The above measurements were made at a chopping frequency of 10 c/s with a bandwidth of 1 c/s. No factors were applied in the calculation of the amount of energy received by the bolometer for the losses due to chopping or absorptions in the air, window, etc.

The time constants in air and vacuum were 5 and 7 ms respectively.

CONCLUSION

The work so far has been limited to producing the actua bolometer element and little attention has been paid to th final mounting. However, the dimensions of the mic support can be readily varied and it is envisaged that th bolometer will finally be housed in a permanently evacuate glass envelope, behind a suitable window, and of a convenien shape to use in a spectrometer or radiometer.

ACKNOWLEDGEMENTS

The work described here has been carried out as part o the research programme of the National Physical Laborator and is published by permission of the Director.

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The design of calorimeters for the determination of ion beam intensities

[*Paper received* 17 *December*, 1956]

By E. R. Harrison, A.Inst.P., Atomic Energy Research Establishment, Harwell, Berks.

Calorimetric methods for determining the total particle flux of ion beams are discussed. Three types of calorimeter are described which, from experience gained with 25–50 mA, 10 keV and 0·2 mA mean, 500 keV proton beams, have proved suitable for this purpose. The sensitivity of the calorimeters can be either calculated from elementary theory, or obtained directly by a convenient method of calibration.

The use of calorimetric methods for determining the total particle flux of ion beams is discussed, and three types of calorimeter are described which have proved suitable for this purpose. The calorimetric method consists of measuring the amount of heat generated per second by a beam incident upon a target; provided the mean energy of the beam is known, the initial particle flux (and equivalent electric current) can then be calculated. This method is most useful when measuring intense ion beams, and the calorimeters described in this paper have been designed from experience gained with 25–50 mA, 10 keV and 0·2 mA mean, 500 keV proton beams.

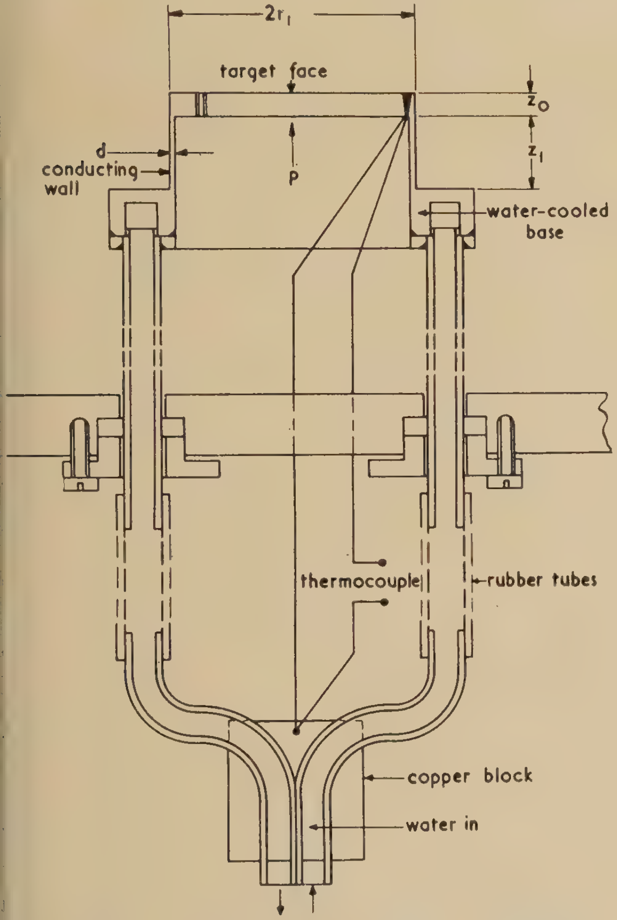
Sanders(1) has pointed out that the calorimetric method is advantageous when the beam contains a fast neutral component of approximately the same energy as the charged particles, and also when residual gas effects and secondary electrons lead to spurious currents of low energy in the region of the target. With intense beams it is particularly difficult to eliminate such spurious currents; a calorimeter is the frequently a more reliable and convenient measuring instrument than a current meter, and at the very least will provid useful supplementary information. The direct measuremen of the current of an unfocused beam immediately below a ion source can be particularly confusing. A calorimete however, measures the total flux of ions and neutrals, an in principle these may be separately estimated by suitabl biasing the calorimeter and thereby altering the energy flu of the charged component. This method of estimating th components in a beam by applying a variable bias voltage obviously restricted to beams of low energy.

Only beams which are approximately axially symmetric a considered in this paper, but calorimeters can be readil designed to suit any kind of moderately focused beam. Thre types of calorimeter which have been used are shown i Figs. 1 to 3. In Figs. 1 and 2, the heat generated at the targe face by the beam is conducted away to a water-cooled bas ıer through a thin wall or skirt, or through a central stem small diameter. The sensitivity of these calorimeters in livolts per watt is found by calibration with a controlled ıt supply; alternatively, the sensitivity in degrees Centigrade watt may be estimated by calculation, and the thermoıples calibrated separately. Fig. 3 shows a continuous-flow e of calorimeter requiring a supply of water of a measured e of flow in which the temperature difference between the ıut and output flow is determined with thermistors.

THE DESIGN OF BEAM CALORIMETERS

\ calorimeter should preferably be constructed from a terial, such as aluminium, which does not readily sputter. should also be designed to have adequate sensitivity and a ıid response with negligible radiation losses, and should be ıable of easy calibration or have the geometry such that sensitivity can be reliably estimated.

n the skirt type of calorimeter shown in Fig. 1, the ıperature is best measured at the edge of the target face, l is then independent of an arbitrary current distribution ın axially symmetric beam normally incident on the centre the target face. Since small asymmetries in the current ribution and alinement are unavoidable, a number of rmocouples, say N, can be equally spaced around the target face and the mean of their temperature used for computing the beam flux. The N, $2N$, $3N$ . . . harmonics are not averaged out by this method, but for small asymmetries the error involved is negligibly small. In the skirt calorimeters used by the author, three equally-spaced thermocouples are used, and by comparing their outputs the beam can be alined along the axis of the focusing and accelerating system. In the stem calorimeter, shown in Fig. 2, the thermocouple is connected to the upper part of the central stem, and the measured temperature is independent of small asymmetries in the beam.



ig. 1. Skirt type calorimeter, showing thermocouple old junction connected to a copper block of the same temperature as the cooling water

Owing to their simple geometry, both types of calorimeter have the advantage that their performance can be readily calculated, often with sufficient accuracy to make experimental calibration unnecessary. With a suitable choice of values for the dimensions, the thermal capacity of the calorimeter is confined almost entirely to the target face, and the thermal resistance is confined principally to the thin skirt or the small diameter stem. The steady state condition and the time constant of the transient state can then be calculated by elementary theory.

In small diameter calorimeters the target face may be made relatively thick without necessarily having a large thermal capacity; the temperature gradients in the face are then negligibly small and the target face thermocouple can be attached to the more convenient points marked p in Figs. 1 and 2. In practice, it has been found that the skirt calorimeter is more suitable for large diameter beams, and that the stem type is best suited for beams of 1 cm or less in diameter. These remarks, however, serve only as an approximate guide since the beam power will have some influence on the choice, and in some circumstances an entirely different type of design may be necessary.

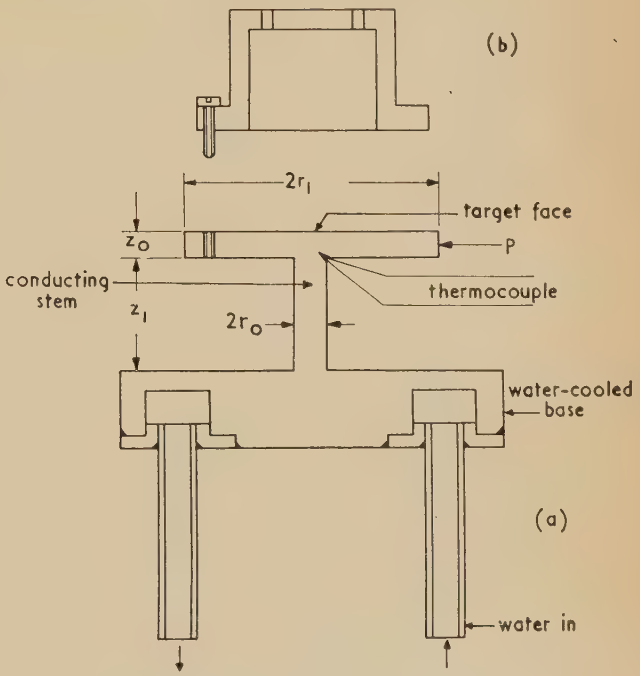


Fig. 2. (*a*) Stem type calorimeter; (*b*) heater box for direct calibration of calorimeters

The continuous flow calorimeter was constructed as shown in Fig. 3. The water flows through a single, labyrinthine passage of small cross-section cut in the target face. As with the calorimeters previously described the components were cemented together with an epoxy thermosetting resin. The advantage of this type of calorimeter is its rapidity of response, and also the sensitivity can be estimated with a greater degree of accuracy than in the case of the skirt or stem types.

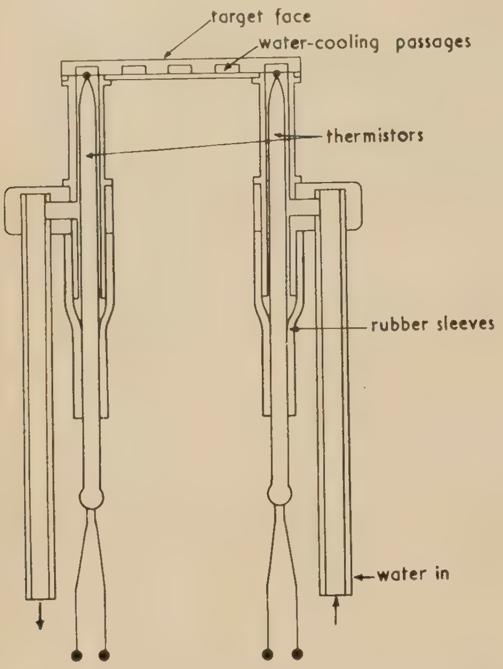


Fig. 3. Continuous flow calorimeter using thermistors for measuring water temperature

CALIBRATION

For the direct calibration of beam calorimeters it is preferable to use a heater box, as shown in Fig. 2(*b*), which is temporarily secured to the target face. For small beam powers (i.e. sensitive calorimeters) a flash lamp bulb with the base removed makes a convenient heating element; for larger beam powers up to 100–200 W the heating element consisted of coiled tungsten wire threaded through steatite beads and coiled up inside the heater box.

Consider first the calibration of the skirt and stem type calorimeters. Most conveniently, the cold junction of the target face thermocouple is connected as in Fig. 1 to a copper block, having the same temperature as the cooling water. Expressing the thermoelectric power by an expression of the form $A + BT$, the effect of fluctuations ΔT_0 in the temperature T_0 of the cooling water amounts to an error of

$$\Delta V/V = 2\Delta T_0 B/[2A + B(T + T_0)]$$

where V is the thermocouple e.m.f. and T is the target face temperature. For copper-constantan thermocouples $\Delta V/V$ amounts to $2{\cdot}4 \times 10^{-3}\,\Delta T_0$ and $2{\cdot}0 \times 10^{-3}\,\Delta T_0$ for values of $T + T_0$ of 10 and 200° C, respectively. For fluctuations of ±5° C in the temperature of the cooling water this error is approximately 1%, and when this lies within the required experimental accuracy one pair of thermocouple wires is sufficient. Since the thermoelectric power is not constant within the required temperature range of, say, 10–200° C the calorimeter is used either in conjunction with a curve plotted from the results of the calibration or, more conveniently, by calibrating a galvanometer scale in beam power, or equivalent beam current where the energy is fixed.

A calorimeter of the type shown in Fig. 1 was designed for a 500 keV proton beam of a mean current of 0·2 mA, and to have a target face temperature of approximately 200° C. It was constructed from 99% pure aluminium, having the dimensions: $r_1 = 0{\cdot}500$ in., $z_0 = 0{\cdot}076$ in., $z_1 = 0{\cdot}310$ in. and $d = 0{\cdot}010$ in., and machined from a single piece of metal with the exception of the lower section of the water-cooled base. Using the values of 0·50 cal $\text{cm}^{-1}\,\text{s}^{-1}\,{}^\circ\text{C}^{-1}$ for the thermal conductivity, 2·71 g cm^{-3} for the density, and 0·21 cal $\text{g}^{-1}\,{}^\circ\text{C}^{-1}$ for the specific heat, given by the suppliers of the aluminium for 0–100° C, one finds that the sensitivity has a calculated value of 1·82° C W^{-1} as compared with 1·91° C W^{-1} found by calibration. The difference, amounting to 4·7%, can largely be attributed to uncertainties in the values of the thermal conductivity and the wall thickness, the latter was determined to an accuracy not better than 2·5%. The time constant of the calorimeter is found to be 3·3 s; the time taken for the temperature to reach 98% of its steady value is 13 s, as compared with 7 min for the calorimeter described by Sanders.

For the continuous-flow calorimeter the thermistors were first calibrated with thermometers and then used in conjunction with bridge circuits of the kind proposed by Beakley[(2)] and McLean.[(3)] With a 1 in. diameter target face a calorimeter of this type had a time constant of 0·2 s for a temperature difference of 10° C between the inlet and outlet water flow and a beam power of 100 W. Using the auxiliary heater box, the mechanical equivalent of heat at 28° C was found to be 4·23 J cal^{-1} without taking any unusual care, thus establishing that the heater box method of calibration can be relied upon for moderate accuracy.

CONCLUSION

The skirt and stem type calorimeters are readily constructed and calibrated, and for moderate accuracies, within approximately ±5%, their performance can be determined by simple calculation. The continuous flow type of calorimeter is less easily constructed and, furthermore, requires a supply of water of a measured rate of flow, but it has the advantage that direct calibration with an auxiliary heat supply is unnecessary.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. L. C. W. Hobbis for several interesting discussions on the subject of beam calorimetry.

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Laboratory and workshop notes

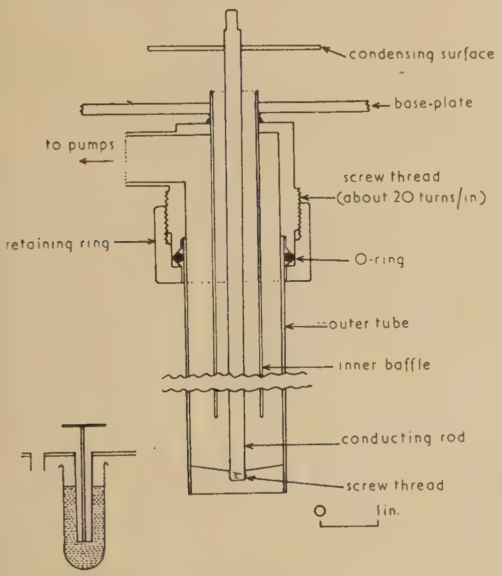
A vapour trap for vacuum systems

3y G. K. T. Conn, M.A., Ph.D.,* and H. N. Daglish, B.Sc., Ph.D.,† University of Sheffield

Note first received 27 February, and in final form 10 *December*, 1956]

any vacuum apparatus there is a danger of contamination vapours and this is particularly serious in demountable tems which can rarely be thoroughly cleaned. A particular l common case is that of a work-chamber in the form of ell-jar, in which a conventional trap will prevent vapour ching the work from the pumps but does little to eliminate our originating inside the bell-jar. An ideal trap is one which the vapour molecules from whatever source can ne directly into contact with a cooled surface. Such a face must be, in the case quoted, inside the bell-jar. issner(1) has described a trap in which liquid nitrogen ses through tubes inside the bell-jar. This is often inconient and a simpler trap is described here, using a principle ich has also been adopted by Pollard.(2)

he condensing surface offers effectively a solid angle of to the work-chamber since it is supported on a conducting , the lower end of which is directly cooled. The design is strated in the figure which shows the central rod of polished per projecting from the outer casing into the vacuum mber. This outer casing is immersed to a depth of some inches in liquid nitrogen. The top of the copper rod ies a large surface on which vapour condenses. The led surface may be extended to form a cold screen round aratus in the work-chamber. The central rod is threaded he lower end so that it is easily removed for cleaning or nging the condensing surface. If experiments require the of sources of heat within the work-chamber these should rly be screened so that direct radiation does not cause ous heating of the condensing surface.



)etails of design of vapour trap for vacuum system. Total length 12–14 in. *Inset*

Although the outer tube, made of a metal of poor thermal conductivity such as nickel–silver, may be permanently attached to the base-plate of the vacuum chamber, the authors have found the demountable seal illustrated both convenient and satisfactory. The vacuum seal is by means of a rubber O-ring and remains effective even when the trap has been cooled for long periods.

The inner baffle tube surrounding the central rod ensures that any vapour from the pump is condensed. If the central rod is removed, the outer tube may be replaced by a Pyrex glass tube to form the equivalent of a conventional, re-entrant trap whenever this is more convenient; this is illustrated in the inset and the diagram.

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Now at the University of Exeter.
Now at the Post Office Research Station, Dollis Hall, London.

An autographic testing machine

By A. A. Barker, Engineering Laboratory, University of Cambridge

[*Note received* 24 *October*, 1956]

An autographic testing machine for drawing load deflexion curves was required by Prof. J. F. Baker to demonstrate at a lecture the behaviour of steel structures when carried through the elastic and plastic ranges to collapse. It was essential that the audience should be able to see the structure under test and also the deflexion curve as it was drawn. These apparently simple requirements proved so difficult to fulfil that it is worthwhile to describe the final successful machine as designed and constructed at this Laboratory.

As can be seen from Fig. 1, the machine consists of a braced steel frame made from slotted handy angle steel. The top

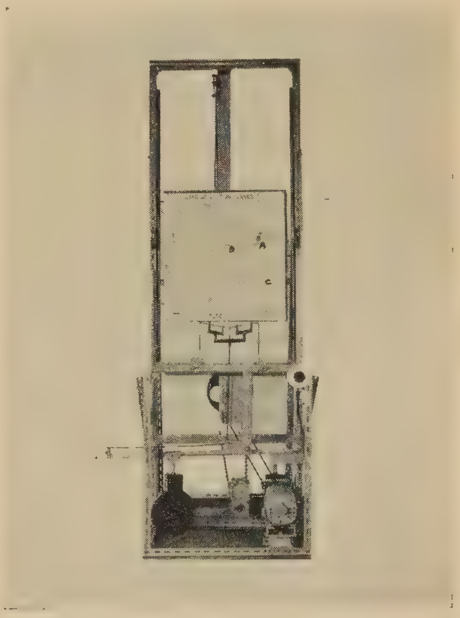


Fig. 1. Autographic testing machine showing load deflexion curves

half of the frame houses a drawing board 20 × 24 in. (to which a sheet of drawing paper is pinned), running in guides employing kinematic principles. This board is driven by an endless chain and counter-balanced. The lower half of the frame houses the loading mechanism, torque amplifier and driving unit.

The loading mechanism consists of a lever carrying a climbing weight of 50 lb with pivots arranged to give 4 : 1 magnification, again driven by an endless chain. A four-point loading rig is attached to the steel structure under test and coupled to the lever by a chain. The torque amplifier input is taken through a rack and pinion drive which follows the deflexion of the structure, while the output is coupled to a large diameter Tufnol grooved wheel carrying a steel tape 0·25 × 0·006 in. thick, giving a magnification of 24 : 1. The other end of the tape, after passing over two pulleys, is attached to a slide carrying a dead-weight loaded piece of charcoal, giving a bold black line on the drawing paper attached to the board. When the machine is set in motion the drawing board and the 50 lb weight on the loading arm are made to travel at the same speed. The deflexion of the structure under test is magnified twenty-four times and recorded horizontally, the energy to do this and overcome the friction set up between the charcoal and the paper being supplied by the torque amplifier, which in turn is driven by the motor driving the loading mechanism.

The driving unit consists of $\frac{1}{4}$ h.p. single phase a.c. motor coupled to a Vickers infinitely-variable speed hydraulic unit. Thus varying speeds of loading can be obtained, and, since the Vickers unit is easily reversible, loads on specimens can be taken off at will during the test. The back view of the apparatus is shown in Fig. 2.

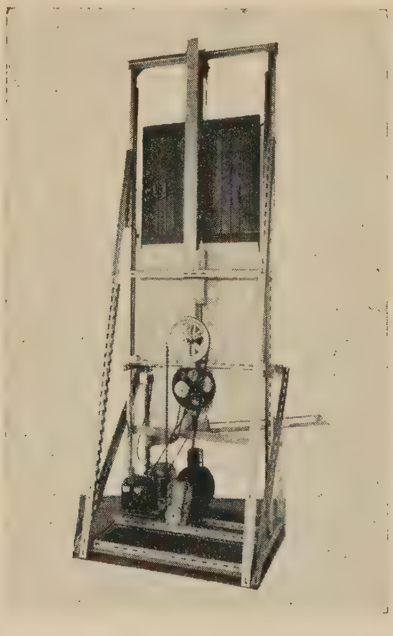


Fig. 2. Back view of autographic testing machine

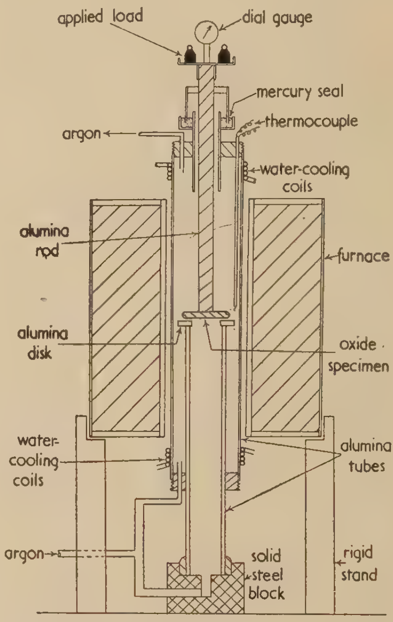
In Fig. 1 a portal frame has just reached its collapse load; the other two curves, *B* and *C*, are from earlier tests on an encastre beam and a simply supported beam respectively, both of the same section, $\frac{1}{4}$ in. square, and length as the beam of the portal.

High-temperature plasticity measurements in controllable atmospheres

By J. D. Mackenzie, Ph.D., A.R.I.C., University Chemical Laboratory, Cambridge

[*Note received* 31 *October*, 1956]

In the course of a study of the oxidation kinetics of iron and its lower oxides, it was found that measurements of the relative plasticity of polycrystalline wüstite, magnetite and haematite at elevated temperatures were desirable. The only apparatus which permits creep tests in inert atmospheres wa reported by Fenner and Willoughby,(1) who modified a conventional rhomb-and-mirror extensometer by the inclusion o a gas chamber. This is unsuitable for small solid specimens the preparation and fabrication to standard shapes of which are difficult. The simple extensometer shown in the figur was therefore developed for use in controllable ambien atmospheres.



High-temperature extensometer

The oxide specimen was placed on a recrystallized alumin disk with a central circular hole of diameter 1·5 cm. Th disk in turn rested on a recrystallized alumina tube rigidl mounted on a solid steel block. Stress was applied b placing weights on a pan connected to a central recrystallize alumina rod 1 cm in diameter. The tubular connecto beneath the pan was encircled by a close-fitting brass sleev and the annular space packed with a lubricant, thus preventin horizontal displacement of the central rod. Creep wa measured by the downward movement of the alumina ro indicated by the 0·0001 in. dial gauge in contact with th pan. Both the dial gauge and the brass sleeve were separatel held in place by mounts directly connected to the wal Before the experiment the apparatus was swept for som hours with argon admitted at two different points, bu during a run only a very slow and constant gas rate wa maintained. The mercury seal permitted vertical movemen of the rod whilst maintaining the inert atmosphere. A Kanthal-wound furnace was used and the temperatur accurately controlled by a Westinghouse Celectray potentio metric-type controller *via* a chromel–alumel thermocouple i act with the heating element. Temperature measurement made by a standardized chromel–alumel thermocouple the hot junction placed adjacent to the sample. Satis- ory results were obtained for the creep of polycrystalline ite at 800–1000° C.(2) No corrections were made for the of alumina, which is only slightly plastic at 1200° C, ltimate tensile strength being 24 000 lb/in.^{2} at 1000° C.(3)

is work was carried out during the tenure of a post- oral fellowship in the Department of Chemistry of ceton University, U.S.A., where facilities were made lable to the author through the kindness of Prof. C. E. henall.

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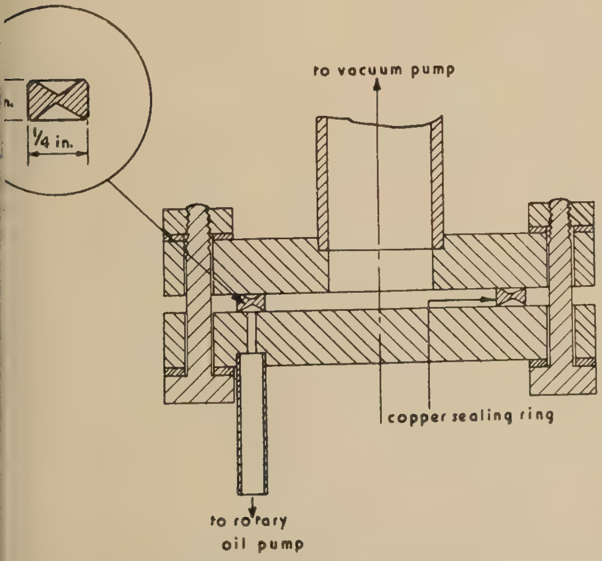
A demountable seal for high vacuum work

y V. A. HEATHCOTE, M.Sc., A.Inst.P., and W. E. READ, Sc., Grad.Inst.P., Research Laboratories of The General Electric Co. Ltd., Wembley, Middlesex

[*Note received* 12 *November*, 1956]

search for a reliable and easy way to construct a ountable seal for high vacuum work, which could be d to 450° C, the authors tried stainless steel knife edges expansion match to copper) pressed into a copper et.(1,2) These were only moderately successful on a eter of $1\frac{1}{4}$ in. and unsuccessful at 4 in. The knife edges carefully polished and the copper gasket also very fully polished and hydrogen furnaced. The use of a ole knife-edge system(3) was considered but not tried.

e problem was solved by the use of standard copper n jointing rings manufactured by Hulburd Patents Ltd. e rings were compressed between two steel flanges and spaces between the contact edges evacuated by means of tary oil pump (see the figure). These seals could be d for prolonged periods at 450° C without showing any sign of a leak. No leak was detectable after baking, using a palladium leak detector. The surfaces of the steel were, in general, ground, but a good turned surface was also adequate. Nickel-plated steel surfaces and "K" Monel surfaces were also successful. Chromium-plating the surfaces was not satisfactory, however.



Details of copper O-ring sealing flanges

O-ring		*Flange*		*Bolts*		*Pitch circle diameter*
Outer diameter	*Inner diameter*	*Diameter*	*Thickness*	*No. of holes*	*Diameter of holes*	
(in.)	*(in.)*	*(in.)*	*(in.)*		*(in.)*	*(in.)*
1	$\frac{1}{2}$	2	$\frac{3}{8}$	8	$\frac{17}{64}$	$1\frac{1}{2}$
$2\frac{1}{2}$	2	$3\frac{3}{4}$	$\frac{1}{2}$	8	$\frac{17}{64}$	3
$2\frac{3}{4}$	$2\frac{1}{4}$	4	$\frac{1}{2}$	12	$\frac{17}{64}$	$3\frac{1}{4}$
$3\frac{1}{4}$	$2\frac{3}{4}$	$4\frac{1}{2}$	$\frac{1}{2}$	12	$\frac{17}{64}$	$3\frac{3}{4}$
4	$3\frac{1}{2}$	$5\frac{1}{2}$	$\frac{1}{2}$	12	$\frac{13}{32}$	$4\frac{5}{8}$
$6\frac{5}{8}$	$6\frac{1}{8}$	8	1	24	$\frac{13}{32}$	$7\frac{1}{4}$

The joints were broken and remade several times, the light film of oxide which formed between the copper contact edges being removed with fine emery paper. Diameters between 0·5 and 6 in. have been used with equal success. The total compression of the rings was 0·030 to 0·040 in. As the rings are quite cheap no attempt was made to re-use them; the only treatment given the rings before use was a light acid etch.

It would appear that the copper forms a diffusion braze with the steel or nickel. The copper rings adhere quite strongly to the steel and very strongly to the Monel and nickel plate. The joint is easily broken by inserting screws into previously tapped holes in the flange and tightening them. The copper ring can also be removed from the flange by a similar process.

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Lattice parameter determination from broad diffraction lines

By F. R. BROTZEN, Ph.D., Rice Institute, Houston, Texas, U.S.A., and E. L. HARMON, Jr., M.S., Case Institute of Technology, Cleveland, Ohio, U.S.A.

[*Note received* 31 *December*, 1956]

Accurate determination of lattice parameters from broad diffraction lines requires some means for resolving the Kα doublet. Various methods have been proposed to effect this separation.(1) The most significant ones are the purely graphical methods proposed by Rachinger(2) and the modification suggested by Finch.(3) Of the two, the latter can be applied more readily.

It was found advantageous, however, to modify Finch's method by substituting a distribution function that would take the slit width into account. This modification assumed that the intensities of both the Kα_1 and Kα_2 diffraction lines followed a Gaussian distribution about their respective angles of maximum intensity.(4) It was convenient to express the angle in units x of the separation between $K\alpha_1$ and $K\alpha_2$ lines. The variation of this separation as a function of diffraction angle θ was negligible over the range of one diffraction line, provided the angle did not exceed about 70°.

Taking the intensity of $K\alpha_2$ line as one-half of the $K\alpha_1$ line, the total intensity distribution would be

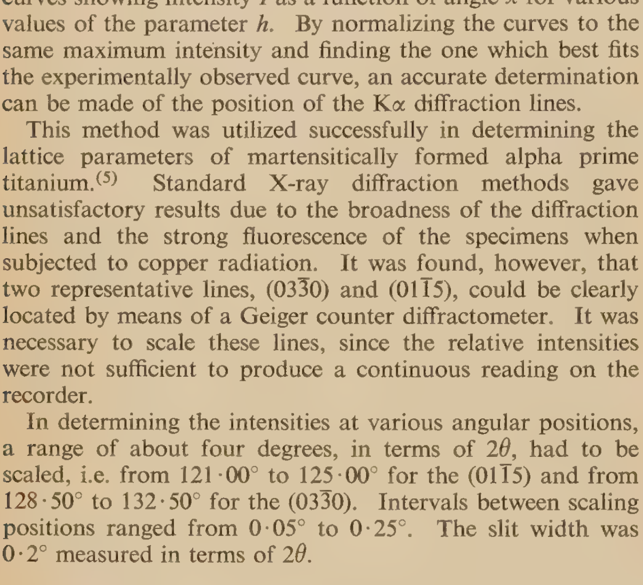
$$I(x) = \int_{x-\frac{1}{2}a}^{x+\frac{1}{2}a} e^{-hx^2}\,dx + \tfrac{1}{2}\int_{x-\frac{1}{2}a}^{x+\frac{1}{2}a} e^{-h(x-1)^2}\,dx$$

where intensity has been integrated over the slit width. Here, h is a parameter of line width, a is the slit width and x is the angular distance from the peak of the $K\alpha_1$ reflexion measured in units of doublet separation.

The above equation can be used to construct a set of master curves showing intensity I as a function of angle x for various values of the parameter h. By normalizing the curves to the same maximum intensity and finding the one which best fits the experimentally observed curve, an accurate determination can be made of the position of the $K\alpha$ diffraction lines.

This method was utilized successfully in determining the lattice parameters of martensitically formed alpha prime titanium.(5) Standard X-ray diffraction methods gave unsatisfactory results due to the broadness of the diffraction lines and the strong fluorescence of the specimens when subjected to copper radiation. It was found, however, that two representative lines, $(03\bar{3}0)$ and $(01\bar{1}5)$, could be clearly located by means of a Geiger counter diffractometer. It was necessary to scale these lines, since the relative intensities were not sufficient to produce a continuous reading on the recorder.

In determining the intensities at various angular positions, a range of about four degrees, in terms of 2θ, had to be scaled, i.e. from 121·00° to 125·00° for the $(01\bar{1}5)$ and from 128·50° to 132·50° for the $(03\bar{3}0)$. Intervals between scaling positions ranged from 0·05° to 0·25°. The slit width was 0·2° measured in terms of 2θ.



Comparison of X-ray diffraction scaling results with intensity distribution curve for a 7·5% vanadium–titanium alloy

Result: $K\alpha$, at 130·28 ± 0·10°; width parameter, $h = 0{\cdot}222$. Radiation, copper; filter, nickel; slit, 0·2° of 2θ; line, $(03\bar{3}0)$.

For each angular position, the scaling time required for predetermined number of Geiger tube counts was recorded from these the intensities, measured in counts per secon were computed. The total number of counts necessary, most cases, ranged from 16000 to 32000 at each scalin position. The background count was subtracted and the n intensities were normalized to give an arbitrary value unity for the maximum. Typical intensities determined b this method are plotted in the figure. Also illustrated in th figure is the master curve which was found to be the best f for the experimental points. It was possible, in this manne to locate the maximum of the $K\alpha_1$ portion of the curve withi about 0·1° of 2θ.

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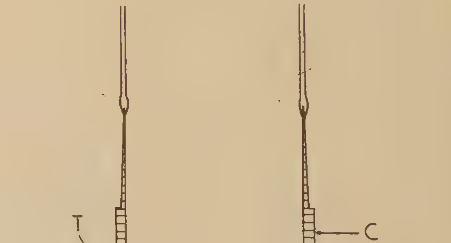
A new demountable ultra-high vacuum joint

By J. Drowart, P. Goldfinger and R. van Steenwinkel, Laboratoire de Chimie Physique Moléculaire, University of Brussels, Belgium

[*Note received* 19 *November*, 1956]

It is often necessary to join Pyrex parts, such as liquid traps, current lead-throughs, or observation windows, to metallic ultra-high vacuum system which is to be pum down to pressures below 10^{-9} mm of mercury. Differe methods have been applied to this end. A metal-to-gla graded seal is in general brazed,(1,2) soldered or welded(2) the apparatus itself or to a metal flange, the latter be joined to the apparatus through a knife edge type of seal gaskets.(3,4,5) To avoid damage of the metal-to-glass se caused by heating to high temperatures during brazing welding operations, another approach has been used in th laboratory.

The outside of the copper cylinder of a copper-to-Pyre



Demountable ultra-high vacuum joint

C, copper cylinder of a "housekeeper" seal; *T*, thread; *P*, profile; *S*, *S*¹, stainless steel supports; *F*, flange; *B*, bolt.

ısekeeper” seal (by the British Thomson-Houston Co.) is threaded on a lathe and screwed into the stainless steel ;e *F* (see figure). By means of this flange and bolts *B*, lat end of the copper cylinder is squeezed against a sharp le *P* on the stainless steel system. It is necessary to n the inside as well as the outside of the copper wall by ings *S* and *S′* to avoid deformation of the copper, which oroughly annealed on account of the initial glass-blowing ation. Suitable dimensions for a 1½ in. “housekeeper” are given on the figure, but they are not critical. Various s and sizes of this seal have been in use in this laboratory over one year. If there exists already a profile on the ıratus that does not match the “housekeeper” seal, it is ible to use an intermediate stainless steel ring with two les, one for the existing gasket and one for the “house- er” seal.

ıis type of joint is easily made, as it requires only the ıanical operation of threading instead of critical and ult operations like brazing or welding. It can be baked cooled, demounted and re-used many times. Therefore sufficient to smoothe the end face by means of fine y paper.

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An instrument for use in ultra-microtomy

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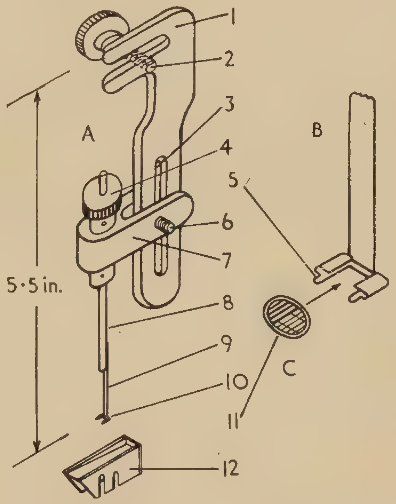
[*Note received* 4 *March*, 1957]

ltra-microtomy of biological materials one of the more ult operations is the removal of serial sections from the r-acetone bath into which they pass after cutting, and to ıtate them on a longitudinal electron-microscope grid. ı the instrument to be described, which can be attached conventional binocular microscope, this operation is e easier.

ıe instrument shown at *A* in the accompanying figure ists of a supporting member (1) which has two screws, of which (2) clamps the instrument to a binocular micro- e and also holds a lamp for viewing specimens by reflected , and the other (6) operating in a slot (3) is used to st and clamp a split metal block (7). This split block es a stainless steel rod (8) which can be rotated by means ıe milled head (4). Soldered to the lower end of the rod is a tongue (9) of fine gauge brass shaped at its end (10) to carry horizontally a longitudinal electron-microscope grid (11). *B* is an enlarged view of the carrier and *C* an enlarged view of a grid.

The carrier (10) is set and remains permanently at the focal distance of the microscope. The grid (11), held by its rim with jeweller’s forceps and viewed through the microscope, can be placed in the horizontal end (5) of the carrier where it remains in focus while being lowered under the surface of the acetone-water in the bath (12) in which the cut section floats.

By the two normal screw-controlled movements of the microscope, vertically and horizontally, together with independent rotation of the carrier, it is easy to locate and lift a section or a ribbon of sections from the bath on the upper surface of the grid.



Instrument for use in ultra-microtomy

An additional movement, namely, rotation of the whole microscope round its vertical axis is used only in locating the carrier over the bath and plays no part in the more delicate operation of lifting the section.

The bath (12), made of plated brass, is clipped to the top of the glass knife close to its cutting edge and is sealed there by a minute quantity of plasticine and sections pass directly to it in cutting.

The grid and its carrier obscures only one-fifth of the visual field of the microscope and does not interfere with the observation of cutting, but it will be understood that the instrument can readily be removed entirely from view, if cutting alone is being observed. When not in use the delicate carrier is protected by an easily detachable cylindrical cover of clear Perspex.

Correspondence

A simple arrangement for obtaining optical transforms of crystal structures

The fly's eye method(1–3) of obtaining an optical diffraction pattern similar to the X-ray pattern given by a crystal, employs an array of unit cells of the crystal structure projected along one of the crystal axes. Recently Hanson and Lipson(4) have shown that four unit cells are enough for the purpose, and they have described an optical diffractometer employing two lenses and the atoms represented by holes punched on an opaque sheet. The possibility of using a single concave mirror has been pointed out by Elliot and Robertson.(5) The author has built up a simple arrangement utilizing only one lens.

The principle of the apparatus is clear from the diagram (Fig. 1). The source is a 40 μ pin-hole, on which is focused light from a 125 W mercury vapour lamp. The light from the source is focused on a screen at the $2f$ position by a high-quality lens 3 in. in diameter and focal length 40 in. If now a diffraction mask is placed in front of the lens, then the diffraction pattern will be focused on the screen. Th exact position of the mask is not important, so long as th complete structure is illuminated, and the pattern is alway in focus on the screen. However, the distance d betwee successive orders in the pattern is related to the unit ce spacing a of the mask by the relation $d = al/\lambda$ where l the distance of the mask from the pin-hole and λ the wave length of monochromatic light employed. The best positio for the mask is therefore close to the lens.

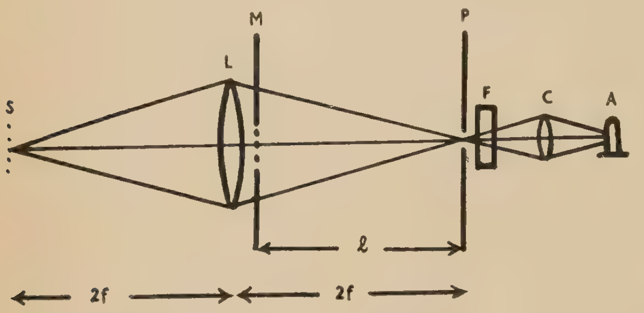


Fig. 1. Diagram of apparatus

A, arc lamp; *C*, condensing lens; *F*, filter; *P*, pin-hole; *M*, mask; *L*, lens; *S*, screen.

The diffraction pattern (enlarged ten times) obtained wit a mask representing four unit cells of sodium chlorate pro jected along a cubic axis is shown in Fig. 2(*b*). A print the mask used is also shown in Fig. 2(*a*). The mask wa obtained by photographic reduction of a drawing made on much larger scale. However, the gelatin in the transparen portions had been etched off, making use of the procedur given in the Kodak data sheet PH5. If this was not done, th variation in the thickness of the gelatin layer produced variou irregularities in the diffraction pattern. Even after removin the gelatin, the variations in the glass thickness remained but these were not serious, provided the size of the whol mask did not exceed about 2 cm square. Over this are the glass plate behaves essentially as a uniform wedge as was verified from an interferometric study made o other specimens of the plate from which the gelatin ha been completely removed. A punched mask is the bes and a pantographic punch is being developed for th purpose.

Kodak B20 plates were found to be very stable in th etching bath and were invariably used, although the glas itself was found to be more uniform with Ilford specia lantern plates. Allowing for the small imperfections due t the glass, the intensities of the spots in the diffraction pattern are found to agree well with the observed $|F|$ values o Zachariasen,(6) which are represented as a weighted reciproca lattice in Fig. 2(*c*). It may be mentioned that this devic could also be used for obtaining ordinary transforms o molecules.(7) It is being applied for the study of cylindrica lattices.

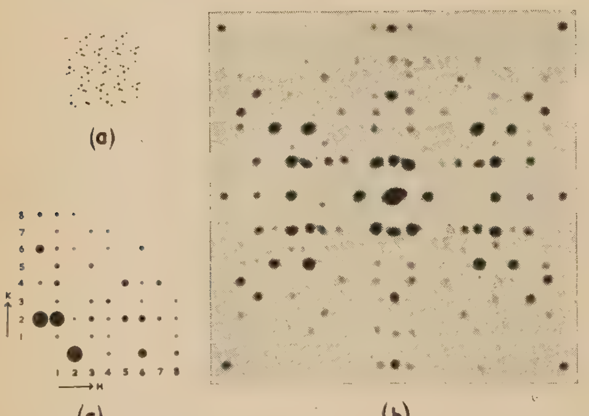


Fig. 2. (*a*) Mask containing four unit cells of the projected sodium chlorate structure. (*b*) Optical diffraction pattern of the above. (*c*) Weighted reciprocal lattice

The author wishes to express his sincere gratitude to Pro G. N. Ramachandran for his help and guidance.

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C. Aravindakshan
(22 October, 1956

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New books

lysis of bistable multivibrator operation: the Eccles-Jordan flip-flop circuit. By P. A. Neeteson. (Eindhoven: Philips Technical Library; London: Cleaver-Hume Press Ltd., 1956.) Pp. 82. Price 15*s.*

919, W. H. Eccles and F. W. Jordan described a new n of trigger circuit employing triodes which was destined nately to become one of the most important unit circuits lectronics.

he original paper occupied three small pages, whilst the k by the present author occupies some eighty-two pages. t is presented a complete analysis of the behaviour of this uit both in respect of its static states and of the dynamic ditions that occur during the transition periods. The ıor points out that little has been published before on latter and he also collects data from all the major papers have been concerned with analysing the circuit.

he matter is well presented and the book is certainly one ch every electronics laboratory and development depart- t should have on its shelves. A. J. Maddock

ineering Analysis: A survey of numerical procedures. By S. H. Crandall. Published: (New York: McGraw-Hill Book Co., Inc.; London: McGraw-Hill Publishing Co., 1956). Pp. x + 417. Price £3 11*s.* 6*d.*

book is one of the Engineering Societies Monographs is based on lectures delivered by the author at Imperial ege, London, and later at the Massachusetts Institute of nology, where he is now an Associate Professor of chanical Engineering. It is about the mathematical treat- t of difficult engineering problems which call for extensive nputation. Each chapter deals with a particular type of neering problem, the first three chapters being devoted iscrete systems with a finite number of degrees of freedom the remaining three to continuous systems. In each n division we find equilibrium problems about steady- e temperature distributions and stresses in elastic frame- ks, for example; eigen-value problems such as arise in rmining natural frequencies of vibration; propagation olems where the state of the system is known at a given e and is to be determined at a future time. Standard nputational techniques, including iteration, relaxation, urbation, variational and finite-difference methods are ribed and applied to each type of engineering problem; means that we find in this book practical methods for solution of algebraic, ordinary differential, and partial erential equations. A special feature is that many nples are given of what is sometimes the most difficult , that of expressing an engineering problem in terms of a hematical model to which computing techniques can be lied. Each numerical procedure is clearly illustrated by worked examples which follow the general discussion. reviewer was particularly attracted by the treatment of method of characteristics. There are 432 exercises, with wers given to many of them. The treatment throughout etailed and is supplemented by valuable references for her reading.

o look upon this book as being of interest only to neers would be to underrate its usefulness. It is more quately described as a textbook of numerical techniques, nged with engineers particularly in mind but full of rest for all who are concerned with the numerical treat- t of practical problems whether as teachers or practitioners. J. Crank

Handbook of semiconductor electronics. Edited by L. Hunter. (New York: McGraw Hill Book Co., Inc.; London: McGraw-Hill Publishing Co., Ltd.). Pp. xxviii + 482. Price 90*s.*

This book is undoubtedly the most complete review of semiconductor technology and circuitry published to date. It has been compiled by thirteen authors, all of them specialists in some branch of semiconductor device development or circuitry. It is divided into four parts; Part I deals with the physics of semiconductor devices, Part II with the technology of device fabrication, and Part III with circuit design and applications. Part IV is a reference section dealing with the principles of circuit analysis and the measurement of device and material parameters.

Being essentially an advanced text for the specialist, it is not suitable for the undergraduate, or the worker entering the field of semiconductor electronics without previous experience. For the worker engaged in semiconductor device development, the sections dealing with semiconductor materials and device fabrication should prove most helpful, although the reviewer would like to have seen considerably more space devoted to the preparation of high purity silicon and its conversion to single crystal form; these important parts of current semiconductor technology have been dealt with rather briefly.

It is perhaps unfortunate that the book should have been compiled before the importance of solid state diffusion as a device fabrication technique became fully apparent; although diffusion techniques are mentioned, they are not given the emphasis which they now deserve. This is an example of a difficulty which must arise when a comprehensive survey is attempted in a subject which is developing as rapidly as semiconductor technology.

This type of difficulty is not so seriously felt in the circuitry sections which, in fact, form the major part of the book. There is a most comprehensive and detailed review of the circuit applications of all types of semiconductor devices, which should be invaluable to the circuit engineer who is beginning to think in terms of semiconductor circuit elements. Not the least attractive feature is a bibliography of some 2,000 references to semiconductor papers, extending from 1936 to 1955.

This book can be recommended to all those working in the field of semiconductor electronics, and is a reference work which should find a place in every semiconductor laboratory. A. A. Shepherd

Tinplate handbook. By W. E. Hoare. 3rd Ed. (London: Tin Research Institute, 1966.) Pp. 44. Gratis.

The new edition of this handbook deals with almost all aspects of the industry, from production to testing and packing. It contains a glossary of technical terms in English, French, German and Spanish and sixteen tables giving technical data. There is a useful section on the applications of tinplate. H. R. Lang

Laboratory glass-working for scientists. By A. J. B. Robertson, D. J. Fabian, A. J. Crocker and J. Dewing. (London: Butterworths Scientific Publications, 1957.) Pp. xiv + 184. Price 22*s.* 6*d.*

This book contains most of the information on materials, glasses, glass-blowing technique and construction of glass apparatus likely to be needed by the amateur working in a scientific laboratory. It contains all and much more than the material available to well-known scientists skilful in the craft in the past. Moreover it also has the special merit that where direct information is not given, very valuable references are provided.

At present few amateurs will have access to a glass-working lathe, one form of which is described. But in the reviewer's opinion its inclusion in scientific laboratories as part o standard workshop equipment is certain to become mor common in future. Amateurs will then discover that b using it they will save themselves much time as well a increase the scope of their achievement. A closer study o its influence on technique will therefore probably be calle for when a second edition of this useful treatise become necessary.

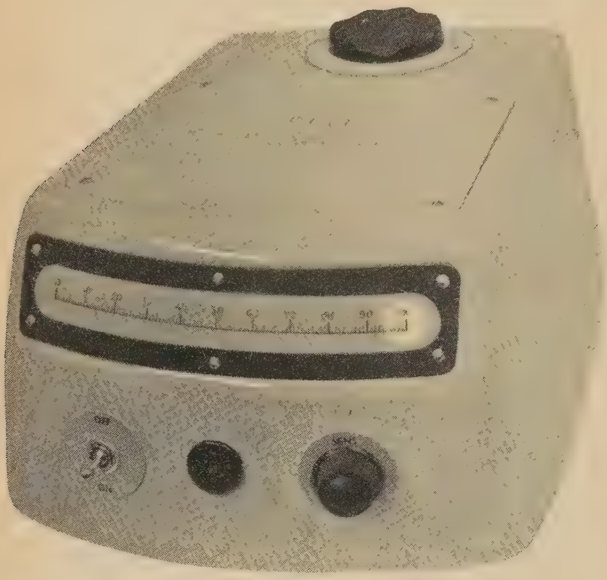
J. H. Burrow

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improve products. The Institute of Physics assumes no responsibility for the statements given below: information for these has bee taken from literature supplied.

Portable spot galvanometer. Evans Electroselenium Ltd., Harlow, Essex.

The "Unigalvo" comprises a taut suspension galvanometer mounted in a sealed plastic body and housed, together with projection lamp, transformer, controls and scale, in an aluminium case. The galvanometer unit is built complete with magnet on a die-cast backbone, the whole being mounted in a dust-proof plastic moulded body and cover. The unit is provided with a clamp for the coil which also relieves the ligament tension, thereby allowing for very rough handling without damage. The body of the unit is pivoted on a base-plate to permit vertical adjustment of the reflected light beam. A large adjustment knob projecting through the instrument case provides smooth and easy adjustment of zero. The unit has a period of 2 s. With the standard coil resistance of 600 Ω the current sensitivity is 330 mm/μA and the critical damping resistance is 15 kΩ. The 4 V projection lamp is supplied by a built-in mains transformer. When the mains switch is in the off position, the galvanometer coil is shorted, thus affording further protection to t suspension. A range switch gives 1/1, 1/10, 1/100 and 1/100 of normal sensitivity.



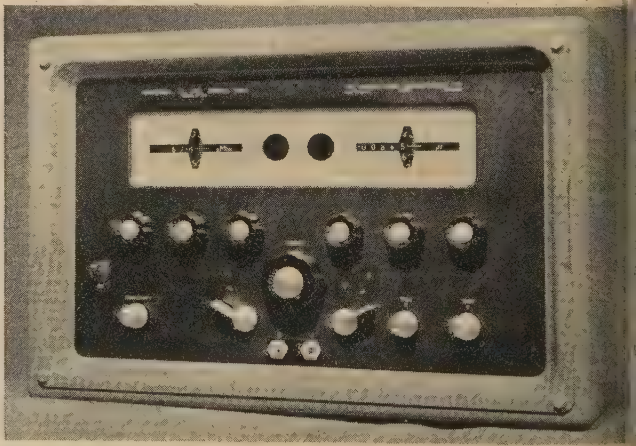
Portable taut suspension mirror galvanometer.

Stabilized power unit. Racal Engineering Ltd., Wester Road, Bracknell, Berkshire.

The stabilized power supply unit type PU.156 employs conventional series stabilizer circuit. It provides a stabilize output adjustable between 200 and 300 V at currents up t 250 mA. The stability is stated to be better than 0·1% a the output resistance is given as 1 Ω. A stabilized output o 15 mA at −150 V, stable to 0·4%, is also available. For th supply of valve heaters, there is an unstabilized a.c. supp of 8·5 A at 6·3 V. The unit may be operated with eith positive or negative earthing. The unit is available eith as a bare chassis or assembled on a standard 19 in. pane with output terminals, meters and controls.

Universal bridge. The Wayne Kerr Laboratories Ltd Roebuck Road, Chessington, Surrey.

The type B221 bridge illustrated in the figure is an accura bridge of advanced design using a tapped transformer a ratio arms. It provides facilities for two, three or fou



Universal bridge utilizing transformer ratio arms minal measurement of impedance or transfer admittance ɜr a wide range at an operating frequency of 10^4 radians/s 92 c/s). Measurement is stated to be unaffected by the pedance of the test leads, which can therefore be of any gth. The instrument is therefore very suitable for the ermination of temperature coefficients of components under t conditions or remote *in situ* measurement. A novel chanism automatically displays the cyphers, decimal and its of measurement. This saves having to apply multiplying tors. The basic range of the instrument covers impedances m 10^4 MΩ to 10 Ω with an accuracy of $\frac{1}{4}\%$. This range ı be extended to 50 μΩ by the use of a low impedance ıpter. The basic impedance range corresponds to capaciıce values from 0·0002 pF to 10 μF and inductance values m 1 mH to very high values. With the low impedance ıpter, the capacitance range becomes 1 μF to 10^5 μF and inductance range 0 to 10 mH. Special adapters are ıilable for use with the bridge for the measurement of ıductivity, dielectric constant and loss factor of solids and ɹids.

cording spectrophotometer. Beckman Division, Beckman Instruments, Inc., Fullerton, California, U.S.A.

e Beckman ratio recording spectrophotometer (model <-2) gives coverage of three spectral ranges—ultra-violet, ible and near-infra-red. In the ultra-violet and visible ıges, the quartz prism and photomultiplier detector allow ɜration down to 200 mμ. In the near-infra-red, the <-2 is said to have more than ten times the resolution ssible in ordinary rocksalt instruments. The natural quartz the Beckman monochromator allows operation to 3·0 μ. Spectra are recorded on 11 × 17 in. chart paper. A panel tch allows the analyst to select any desired recorded chart sentation; linear transmittance, linear absorbance, or direct energy. Abscissa presentation is linear in prism rotation, h a non-linear wavelength scale which expands the ultralet to half the scale, giving a stated substantial gain in uracy. Linear wavelength presentation can be added at ra cost.

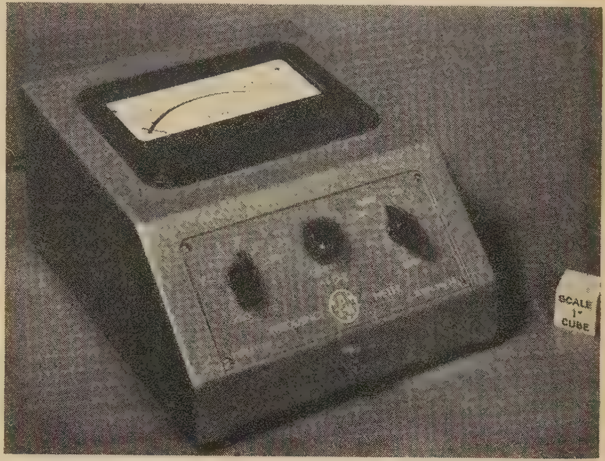
Small differences between nearly identical samples can be orded directly on the DK-2, with higher sensitivity than is ssible by visual comparison of curves. Differential measurents are made with full-scale energy, and at higher signal-toise ratios than would be possible in corresponding direct sorption measurements. Special chart transmission scales y be selected by a panel switch.

Standard printed charts are available for the most common ıges on translucent paper. Gummed wavelength tapes available to affix along the abscissa for various wavegth scale expansions, or reference marks can be made ectly on the chart during or after the run. The Beckman me attachment makes the DK-2 into a direct-reading ission spectrograph. All that is needed is the standard del DU flame attachment and a simple conversion kit.

A "time-drive" attachment equips the DK-2 for reaction e studies. In this instance, transmittance or absorbance is orded without changing the wavelength.

ctronic frequency meter. British Thomson-Houston Co. Ltd., Rugby.

e meter illustrated in the figure gives direct readings of quency from 15 c/s to 100 kc/s in six switched ranges. e instrument incorporates junction transistors and germanium diodes, and the frequency under test is shown on the linear scale of a moving coil meter. The basis of the instrument is a saturating transistor amplifier which charges and discharges a capacitor on each cycle of the input voltage. As the mean current through the capacitor is proportional to the input frequency, it can be rectified and shown directly in terms of c/s on the scale of a d.c. moving-coil meter. A rotary switch selects any one of six frequency ranges with full-scale deflexions of 300 c/s, 1, 3, 10, 30 or 100 kc/s respectively. The makers claim an accuracy better than 1% of full-scale deflexion on all but the highest range. On the highest range, this accuracy is attained up to about 70 kc/s, but because of the limiting transistor characteristics, measurements above this frequency may be subject to an inaccuracy not exceeding 5% at 100 kc/s. The instrument operates with input voltages between 0·1 and 500 V, a switch being provided to select one of two appropriate inputs to the amplifier to suit the applied voltage. The current drawn from the source being measured is 40 μA for a sine-wave input and up to 110 μA for other waveforms.



Portable frequency meter

The meter is primarily designed for use with the internal battery as a source of reference voltage. The drift is then less than 1% for a 10% variation in mains voltage supply. It is possible to make use of the mains voltage as a source for reference but more frequent calibration is then necessary.

One application of the instrument is for measuring speeds of rotating shafts by connecting the input to a photo-conductive cell. A combined photo-electric head and light source will be available as an accessory, and by focusing this on to a suitable mark on a rotating shaft a direct reading can be obtained of the speed of the latter.

Narrow band interference filters for use in the ultra-violet region. Barr and Stroud Ltd., Anniesland, Glasgow, W.3.

Narrow-band interference filters can now be produced to operate in the region 2200 Å to 4000 Å. For use in the visible spectrum silver films are used as the reflecting materials, and a ratio of peak transmission to background transmission of the order of 300 is obtainable, together with a bandwidth (half peak to half peak) of the order of 80 to 120 Å. Silver fails at wavelengths of approximately 3200 Å, since in this region reflectivity falls to a very small value. The region of the mercury arc transmission at 3660 Å does fall into the useful range and silver/dielectric filters for isolation of this line can be supplied.

It has been found that by special methods of deposition certain other metals, or combinations of metals, can be used as reflectors in the region 3200 Å to approximately 2200 Å and that although the ratio of reflexion to absorption has not, so far, been made as high as is desirable, it can be made high enough to give a ratio of peak transmission to background transmission of the order of 30, with a bandwidth of the order of 160 Å. Unwanted peaks are customarily eliminated by absorption, using an auxiliary filter. Unfortunately in the ultra-violet region the number of auxiliary filters available is very small, and this limits the "order" of the interference filter which can be used. Strong efforts are being made to improve and increase the number of auxiliary filters and to develop other methods of removing unwanted peaks. No auxiliary filters are yet available for filters having peak transmission at wavelengths shorter than 2530 Å approx.

It will be appreciated that accurate control of characteristics in the non-visible part of the spectrum presents a difficult problem. It is hoped that in most cases users will be willing, if necessary, to tilt the filter in the optical system to a maximum of about 25° off axis in order to obtain maximum transmission at the desired wavelength. Where a tilt cannot be tolerated this should be stated when ordering. Filters cannot, at present, be supplied in sizes greater than 2 in. diameter, and 1 in. diameter will be standard.

For wavelengths longer than 2800 Å a cover glass, which may be the auxiliary filter, is cemented on to the filter to act as a protection. For wavelengths shorter than 2800 Å, since optical cements are strongly absorbent and cannot be used, filters will be supplied either in permanent mounts with sealed-in protective cover, or in temporary holders for transit. Holders can be made to specification if required.

Filters for use in the ultra-violet should at all times be protected from damp and from any likelihood of attack by salt atmosphere or corrosive gases. This applies particularly to uncemented filters.

The materials forming the actual filter are, so far as tests and previous experience can tell, not affected by ultra-violet light. The base materials and the auxiliary filters are also believed to be durable under normal conditions for use, but at this stage no absolute guarantee for a period of years can be given as user-conditions are not yet defined.

Refractometer for continuous monitoring of liquids. Consolidated Electrodynamics Corporation, 300 North Sierra Madre Villa, Pasadena, California, U.S.A.

This refractometer has been designed to monitor continuously the refractive index of liquid process streams in refineries and chemical plants. Known as the type 38–202 Consolidated-Phillips process refractometer, it is an improved version of an earlier type.

The instrument is designed for continuous operation under adverse environmental conditions. The entire electronic and optical system is housed in a pressed-steel bell to provide explosion proofing for hazardous locations. The refractometer is simple, compact and requires only a 2 × 4 ft floor area.

Refractive index, which is related to density, provides a direct indication of relative composition changes in binary mixtures. In a complex process stream a binary mixture can be approximated when all but one or two key components remain reasonably constant. The refractometer measures the difference in refractive index between a sealed-in liquid standard and a flowing sample drawn directly from a process line. This measurement is based on the refraction of a ray of light passing from one medium to another of different refractive index. Beam deflexion is proportional to refractive index difference and is readily measured by an optical servo-system. A telemetering circuit provides a servo-signal for strip- or circular-chart recording, or for direct control.

The manufacturers claim that maximum full-scale sensitivity is 0·001 refractive index units, while minimum full-scale sensitivity is 0·20 refractive index units. Reproducibility of sample reading is $\pm\frac{1}{2}\%$ of full-scale reading. The indicator knob on the front panel is calibrated in arbitrary units of 0 to 300. For most applications the midpoint of the indicator scale is set to correspond to the refractive index of the "standard" sample to permit observing both plus and minus deviations of the flowing sample. Full-scale range is preset prior to installation by appropriate choice of refractor block and sample prism angle.

Counting sub-units. Ericsson Telephones Ltd., Instrument Division, High Church Street, New Basford, Nottingham.

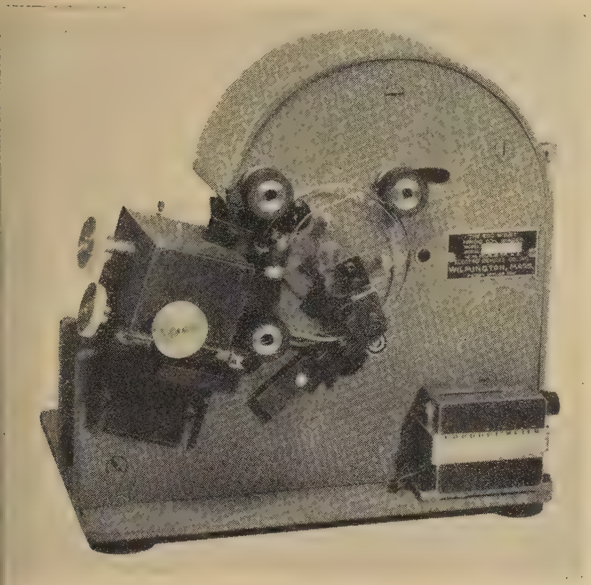
The plug-in counting sub-units are being made so that a wide variety of instruments may be quickly assembled by a "building-block" technique. The basic units either available or under development cover various counting speeds from 5 c/s to 200 kc/s. Speeds up to 5 c/s are counted on resettable or non-resettable electro-mechanical registers, while speeds up to 350 c/s are obtained on Dekatron units employing cold cathode tube coupling stages. For speeds up to 20 kc/s the Dekatron units utilize a hot cathode drive stage; Binary units are capable of counting speeds up to 200 kc/s. The range of units includes input, output and control units and a 1 kc/s valve-maintained tuning fork oscillator for timing and tachometry.

A seven-digit counter assembled from sub-units. The assembly has an input pulse rate of 4 kc/s

Toroid coil winder. Electro Devices Co. Inc., 580 Main Street, Wilmington, Mass.

By winding off the inside of the shuttle instead of the top, the "Midjet" toroid coil winder enables coils to be wound having an inside diameter as small as $\frac{3}{32}$ in. The maximum finished coil diameter is 1 in. and the maximum height, measured ng the toroid axis is ½ in. A range of wire sizes from 30 46 gauge may be used.

The core can be completely covered or the wire may be lt up in any type of sector. Multiple windings can also wound with the multiple leads separated. The winding ed, throughout the entire range of wire sizes covers a ge from 0 to 200 turns/min. It is claimed that fine wire be wound at maximum speed without breaking the wire.



Toroid coil winder

Polished winding guides confine the wire to a plane between shuttle and the core. The wire is passed through a dened and highly polished vent in the shuttle to prevent ks and loops.

t field microscope objectives and wide field eyepieces. Ernst Leitz, G.M.B.H., Wetzlar, Germany.

ssrs. Leitz are now manufacturing objectives which have ery flat field and are simultaneously highly corrected. The ectives are very advantageous for colour photomicrophy.

They are calculated for a mechanical tube length of mm and should be used with periplanatic eyepieces or new Leitz wide field eyepieces described below. The range of objectives are (i) a 4× n.a. 0·10 objective 41·5 mm focal length; (ii) a 10× n.a. 0·25 objective of 9 mm focal length; (iii) a 40× n.a. 0·65 objective 4·63 mm focal length; and (iv) a 100× n.a. 1·32 oil mersion objective of 1·32 mm focal length.

The oil immersion objective has a long free working distance wing all of the objectives in the series to be made parfocal. intermediate adaptor is available to use the flat field Leitz objectives together with the Leitz ordinary objectives on the same nosepiece which compensates for their longer mounts. All the objectives have surfaces treated with anti-reflexion coatings.

The Leitz wide field eyepieces fit the standard microscope drawtubes and are specially designed for use with the Leitz flat field objectives or with such for which in the past periplanatic eyepieces were recommended. The surfaces of the components of the eyepieces are treated with anti-reflexion coatings. The series comprises four eyepieces of magnifications 10×, 16×, 20× and 25× with angles of view of 44°, 52°, 51° and 53° respectively.

Transistor tester. Mullard Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

The L264 tester enables three of the more important junction transistor parameters to be measured. The instrument makes measurements with d.c., and the results are presented as direct meter readings. The base-collector short-circuit current gain, a', is measured by observing the collector current produced by a suitable known base current and transcribing it into a direct meter reading of a' on a scale of 0/100 accurate to 5%. The standing current is backed off in the collector current meter. The d.c. collector current for zero base current, $I'_{c(0)}$, is measured directly, since it is substantially independent of collector voltage. The metered collector voltage supply can be adjusted over the range 0–20 V and $I'_{c(0)}$ can be measured in six ranges from 0–2·5 A with an accuracy of 5%. The collector-emitter turnover voltage for zero base current is measured by applying a relatively high voltage to the collector *via* a resistance and reading the turnover voltage directly on a meter. The feed resistance and voltage supply can be varied to give three ranges of collector dissipation, viz. 2·5, 25 and 250 mW, the ranges of turnover voltage being 0–18 V on the lowest range and 0–85 V on the higher ranges.

Digital pulse delay generator. Racal Engineering Ltd., Western Road, Bracknell, Berkshire.

This generator has been designed to produce precision delays between input and output pulses in the range 3 μs to 1 s, with an accuracy of 1 μs. In principle, the instrument consists of a pulse generator of repetition frequency 1 Mc/s, gating circuits and decade counters. The operation is as follows. The time delay required, for example 4500 μs, is set up on decade switches. Though the number 4500 would appear on the switch indicators, the number set up in the counter circuits would be the complement of this, i.e. 5499. When the start button is pressed, or an external pulse applied, a gate preceding the first decade opens and the 1 μs pulses start counting up. After 4500 pulses have been counted, the decades will have returned to zero. This closes the gate and produces an output pulse. The generator can be supplied with 4, 5 or 6 decades, having ranges of 9999, 99 999 or 999 999 μs respectively.

Notes and comments

British Conference on automation and computation

At the invitation of The Institution of Civil Engineers, The Institution of Mechanical Engineers and The Institution of Electrical Engineers, exploratory Conferences were held on 6th March and 16th April, 1957, as a result of which the representatives of some twenty organizations, with interests in the fields of automation and computation, approved proposals for closer collaboration, and agreed to recommend them to their Councils for adoption. The proposals, if accepted by the bodies concerned, will result in the setting up of a British Conference on automation and computation which will be organized in three groups of Societies, having the following fields of interest:

> *Group A.* The engineering applications of automation techniques; *Group B.* The development and applications of computers, automatic controls and programming techniques; *Group C.* The sociological and economic aspects of automation and computation procedures.

The following bodies would be invited to act as the conveners and sponsors of the three groups:

Group A.

Convener: Institution of Mechanical Engineers; *Additional Sponsors:* Institution of Civil Engineers, Institution of Chemical Engineers, Institution of Electrical Engineers, Institution of Production Engineers.

Group B.

Convener: Institution of Electrical Engineers; *Additional Sponsors:* Institute of Cost and Works Accountants, Institute of Physics, Office Management Association, Society of Instrument Technology.

Group C.

Convener: British Institute of Management; *Additional Sponsors:* Industrial Welfare Society, Institute of Cost and Works Accountants, Institute of Personnel Management, Institution of Production Engineers.

An essential feature of the proposals is that liaison between the groups should be established on a permanent basis from the outset, and it is foreseen that the central unit of the Conference which will be established for this purpose will undertake such other duties as may be deputed to it by the groups; for example, the preparation of periodical digests of published papers falling within the general fields of automation and computation.

All societies and institutions interested in the subject will be most welcome to support the activities of the Conference by applying for membership of the appropriate group or groups. Further information may be obtained from the Secretary, The Institution of Electrical Engineers, Savoy Place, London, W.C.2.

The Board of the Institute of Physics has accepted the proposals and appointed Dr. A. D. Booth and Dr. H. R. Lang as its representatives to Group B; they were its representatives at the exploratory Conferences.

British Standards Institution Yearbook, 1957

The Yearbook of the British Standards Institution has just been published. As usual, 400 pages of this 480 page publication are devoted to a complete numerical list of the British Standards and Codes of Practice current on the 1 January, 1957. These total approximately 3000.

Apart from its main purpose as a reference directory to all current British Standards, the Yearbook contains other information about B.S.I. and the services it offers, including notes on the British Standards mark of approval (the Kite) and the standards to which it is applied. Other informatio covers lists of addresses in the United Kingdom and overseas where complete reference sets of all British Standards can be consulted, while the Yearbook also contains a comprehensive index in which all standards are listed according to subject.

Copies of *B.S.I.'s Yearbook*, which is an invaluable reference work to users of British Standards, have been sent free to all the Institution's subscribing membership, who may purchase additional copies at the published price of 15*s.* less members' discount. Non-members of the Institution may buy at the published price plus 1*s.* 6*d.* for postage and packing.

Erratum

In the paper by G. H. Rayner and L. H. Hall on page 196 of the May issue of this *Journal* the letters beneath the sections of Fig. 8 should read as follows: For (*a*) read (*c*); for (*b*) read (*d*); for (*c*) read (*a*); and for (*d*) read (*b*).

British Journal of Applied Physics

Contents of the June issue

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ORIGINAL CONTRIBUTIONS

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The heating of fluorescent screens bombarded by electrons. By G. D. Archard and P. A. Einstein.

The penetration of irregularly-shaped particles through an airborne-dust elutriator. By J. G. Dawes, G. K. Greenough and J. S. Seager.

Electron microscope and diffraction studies of 7% chromium–molybdenum steels. By Betty E. Williams.

The movement of the second crossover potential of insulators. By A. B. McFarlane.

NOTES AND NEWS

New Books

Notes and comments

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The Physical Society's Exhibition—London, 1957

By E. J. Harris, D.Sc., D.I.C.

A survey is given of newer developments of instruments and apparatus exhibited.

Physical Society's 41st Exhibition was held in the two s of the Royal Horticultural Society, in London, from 28 March last. The following survey will be mainly con- ed with newer developments of instruments and apparatus bited; fuller details will be found in the Handbook of ntific Instruments and Apparatus, published in connexion the Exhibition and obtainable from The Physical Society, owther Gardens, London, S.W.7, price 7*s.* 3*d.*, including age.

he most noticeable trends were in the improvement in gn and extension of application of semi-conductors to e more efficient yet smaller rectifiers and transistors. latter, together with miniature magnetic components of imetre size, are used to make up storage units for com- rs. Much effort has gone into presenting information in al form; this is often coupled with a printing out device. omatic controllers for chemical and nuclear processes attained a complexity which put them beyond the scope e non-specialist: it seems doubtful, however, if they include new principles of basic interest.

mong the University exhibits was a portable galvanometer lifier for the investigation of earth currents and a magneto- er for the investigation of rock specimens, in which the ple is spun by a simple air turbine made of Perspex in the re of a pick-up coil (shown by the University of Durham). at cathode-ray tube designed by Dr. Gabor is the subject ork at Imperial College; models were shown. As usual, ice and other Government laboratories provided a wealth nteresting material, some of which will be mentioned in following sections.

athode-ray tubes. A number of firms are using post xion acceleration applied across a helically deposited tor running on the inner surface of the tube between the assembly and the face.

our- and eight-gun tubes were shown by Twentieth Century tronics Ltd. Tubes with combined electrostatic and netic deflexion can be used to multiply functions; the n is subjected both to an electric field across one pair of es and to an axial magnetic field, corresponding to the ective functions. The beam is held in position by an ric field generated by a feed-back circuit controlled by a ctor system and applied to the other pair of plates; this represents the required product (General Electric Co.). A tube in which the beam is constrained to follow the ile of a collecting plate by applying a fed-back potential rence to the deflectors can be used as a function generator neral Electric Co. Ltd.). The same firm showed a fre- ncy multiplier with rotating beam picked off by a number lectrodes, and a computer storage tube in which charges tored on an insulated surface and continually regenerated. short lasting events can be used to obtain useful xions by feeding them between a helix and a cylinder ted in the cathode-ray tube so that the signal forms a elling wave with velocity equal to that of the electrons he beam (General Electric Co. Ltd. and U.K. Atomic gy Authority).

A photoconductive television camera tube (Emitron 10667) is made by E.M.I. Electronics Ltd.

Chemical apparatus. Automatic recording of gas composition has been devised for a number of gases. Carbon monoxide is determined after oxidation to carbon dioxide by absorbing the latter in sodium hydroxide and measuring the conductivity (National Coal Board). The same principle can be applied directly to a number of other gases (J. W. Towers and Co. Ltd.). Carbon dioxide can be measured by its infra-red absorption (Infra Red Development Co. Ltd.; Sir Howard Grubb, Parsons Ltd.), or by measuring the velocity of sound (Sir Howard Grubb, Parsons Ltd.) or the audio-frequency at which a cavity containing the gas resonates (Dr. Stott, Medical Research Council). Sulphur dioxide evolved during combustion of sulphur-containing oils is titrated with iodine (as iodate) in an apparatus made by W. G. Pye and Co. Ltd., the rate of gas evolution controls the progress of the combustion. Sulphur trioxide in gases can be monitored by observation of the turbidity caused when a known volume of gas is drawn through isopropanol which is then mixed with a barium solution (demonstrated by the Fuel Research Station). A colorimetric method, using eriochrome black as indicator has been applied to continuous observation of water hardness by Nash and Thompson Ltd. Baird and Tatlock Ltd. make a device for continuous check on uranyl ion concentration as is required in ion exchange extraction processes. Automatic titration methods depending on the use of suitable electrodes in the fluid and electromagnetically operated burette tap were shown by Baird and Tatlock Ltd. and by Electronic Instruments Ltd. The latter firm also displayed a variety of special electrodes, and a coulometric method of analysis in which a measured amount of electricity is used to bring the system to an end point determined by a p.d. across suitable electrodes. A square wave polarograph of high sensitivity is made by Mervyn Instruments Ltd. A densitometer using a special float with electric pick-up for position indication was shown by W. G. Pye and Co. Ltd. A level indicator for conducting liquids (e.g. liquid sodium) employs the liquid as variable short in a co-axial line whose resonant frequency is measured (U.K. Atomic Energy Authority). A float operated potentiometer (Plessey Co. Ltd.) can be used for level indication and control.

The National Research Development Corporation have taken up a design for a burette in which drainage error is eliminated (Fig. 1). The burette is made of precision bore tube and has a free floating glass piston of density close to that of the fluid being used. The piston is ground to fit the tube and moves up and down with the liquid level so it defines the volume of the liquid. A vernier scale is engraved on the float. A plastic burette tap which will not stick, and which permits fine control of volume is made by Townson and Mercer Ltd. For halide determination by an electrometric method depending on the change of potential between platinum and silver electrodes, A. Gallenkamp and Co. Ltd. make a set which includes a burette with sealed-in electrode and the indicating unit.

An apparatus for filling a set of pipettes and then delivering an accurate volume into a number of vessels may interest hospital and other routine laboratories; it is being developed by Nash and Thompson Ltd. under a National Research Development Corporation licence. It deals with volumes of between 0·01 and 1 ml.

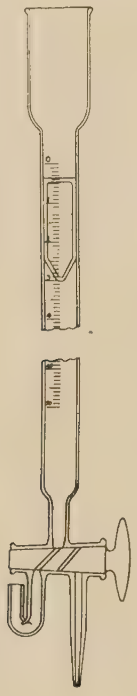

Fig. 1

Furnaces for use at up to 1700° C with platinum windings are made by Johnson Matthey and Co. Ltd. who also showed a range of noble metal thermocouples. Couples between palladium/gold and iridium/platinum have a high thermo-e.m.f. and are suitable for use at up to 350°. A micro-furnace for the rapid combustion of samples in elementary analysis is made by Baird and Tatlock (London) Ltd. The tube has baffle plates to ensure complete oxidation and requires no copper oxide.

Measurement of furnace temperature can be carried out by comparing the energy received on a photocell with infra-red sensitivity such as lead sulphide with that received from a light source which is controlled to give zero difference. A beam chopping system is used. Pyrometers of this type were shown by The British Thomson-Houston Co. Ltd. and the General Electric Co. Ltd.

A separation of the rare gases takes place in a d.c. discharge tube. This phenomenon can be made the basis of a sensitive method for analysis of binary mixtures as was shown by the General Electric Co. Ltd.

Investigation of the fluorescence properties of materials is becoming important and various fluorimeters were shown by Evans Electroselenium Ltd., Electronic Instruments Ltd. and Unicam Instruments (Cambridge) Ltd. The instrument made by the latter firm includes quartz prisms for monochromator and detector, a xenon arc lamp is used as source. It can be converted to a double monochromator.

A. Gallenkamp and Co. Ltd. are developing an adiabatic bomb calorimeter which obviates the need for heat loss corrections. Thermistors are used to detect a temperature difference between inner and outer vessels and the differenc is kept minimal by feeding heat into the outer vessel from a electric circuit.

Balances with a knob operated weight adjustment an scale display of milligrams were shown by Stanton Instru ments Ltd., J. W. Towers and Co. Ltd., and L. Oertling Lt A balance in which the loss of weight which takes place whe the sample is dried with infra-red radiation *in vacuo* is mad by Townson and Mercer Ltd. An apparatus which simu taneously records weight and temperature during the heatin of a specimen is available from Stanton Instruments Ltd.

Vapour phase chromatography of hydrocarbon and othe mixtures is carried out on celite column using thermal co ductivity of the effluent as detector of the fractions i apparatus shown by Casella (Electronics) Ltd. and W. G Pye and Co. Ltd. When radioactive substances are used o chromatograms it is useful to have a scanning device to loca the spots. A strip scanner is made by Labgear Ltd. whic provides a printed record. An experimental two-dimension scanner was demonstrated by the National Institute f Medical Research.

Tongs and other tools for remote handling of radioact substances were displayed by General Radiological Ltd.

Counting/scaling apparatus. Counting units by Phili Electrical Ltd. incorporate a combined counting and in cating tube (the E1T) which is a miniature cathode-ray tu Each of ten positions on the tube wall are illuminated in tu by the beam, which is switched by the incoming pulses. high-speed unit, a standard unit and a compact unit f predetermined counts or time with built-in h.t. supply a made. Preset time or counts is obtainable from units ma by Labgear (Cambridge) Ltd. and Ekco Electronics Lt a printing out unit is also available from Labgear Lt Transistorized scalers were shown by Dynatron Radio Lt and Mullard Ltd. There were several portable transistori ratemeters in which all supplies are derived from a sma battery (Ericsson Telephones Ltd., Burndept Ltd., Pan Equipment Ltd. and General Radiological Ltd.).

A bidirectional scaler which will either add or subtract made by Ericsson Telephones Ltd.; the same firm make pulse adding unit for operating several pulse sources into single scaler. Special dekatrons for count rates of up 20 kc/s have been used in the early stages of several scalers.

D.c. amplifiers. Most, if not all, of the firms who man facture cathode-ray oscilloscopes now provide direct coupl models. These differ in the gain which is available and in t care which has been taken to make them insensitive to "i phase" signals applied to the input. It would be useful figures for maximum limits of drift were quoted.

An amplifier using conversion to a.c. followed by amp fication and rectification with negative feedback of the ou put is made by Nash and Thompson Ltd. It has a noise lev of about 1 μV and a band width of 10 c/s. A transportab electrometer valve amplifier is made by Automatic C Winder and Electrical Equipment Co. Ltd. Units wi vibrating elements are made by Ericsson Telephones Ltd. an Electronic Instruments Ltd. Magnetic amplifiers wi 20000 gain and drift equivalent to 3×10^{-11} W were sho by Electro Methods Ltd.; larger magnetic amplifiers suita for motor control were displayed by W. H. Saunders (El tronics) Ltd.

Engineering devices. An electronic comparator with accuracy of 10^{-5} in. is made by Southern Instruments L One method of obtaining an accurate indication of line position, such as is required for the control rods of reacto is to make the shaft of ferromagnetic material shaped so have recurrent pole pieces. The coarse indication is tained from the amount of core which the rod provides in transformer (Fig. 2), while fine indication is obtained m a primary and three spaced-out secondary solenoids ich determine the position of the nearest pole with spect to them (forming a linear selsyn) (U.K. Atomic ergy Authority). A linear position indicator depending on the mutual inductance between raster elements was monstrated by Plessey Co. Ltd. It has one element divided o poles spaced 0·1 in. apart, positioning can be repeated within 25 μin.

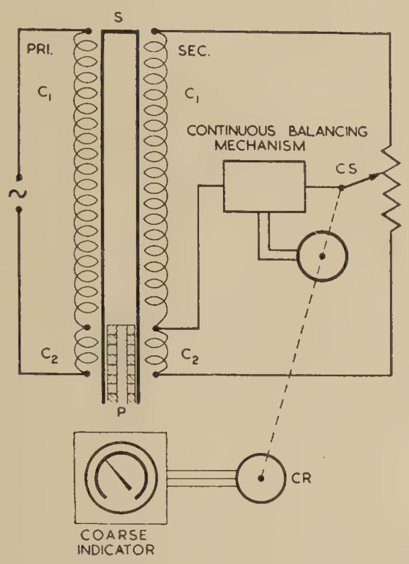

Fig. 2

A spring system which has nearly zero stiffness at a par-ular load was shown by the Royal Aircraft Establishment. is understood that the National Research Development rporation will develop the idea. It can be applied to such ferent purposes as antivibration mounting or to make a ing balance with high sensitivity to deviations from a tical weight. The latter arrangement would be suitable for duct control.

For the metallurgist there was a small induction furnace ich takes samples of up to 5 lb (Radio Heaters Ltd.). wards High Vacuum Ltd. showed an arc melting furnace ich operates *in vacuo* or in a low pressure of argon. Use of conates as transducers for ultrasonic generation doubles ciency and the units can operate at up to 250° C (Radio aters Ltd.). Strain and acceleration measurement by means barium titanate elements was demonstrated by General ctric Co. Ltd. Elements depending upon resistance and luctance changes are made by J. Langham Thompson Ltd. extensometer accurate to 5 μin. and capable of being set a desired range was shown by C.N.S. Instruments Ltd. aft speed transducers, including one with a photoelectric k-up head, were demonstrated by Racal Engineering Ltd. Use can be made of a source of β-radiation spread over a table area to monitor the profile of a material which is ng processed or extruded (Isotope Developments Ltd.).

An ultrasonic drill or engraver is being developed by llard Ltd. It will drill holes down to 0·007 in. diameter, resonant at 27 kc/s and has reciprocating amplitude up 0·002 in.

Flame photometers and colorimeters. In addition to well-own flame photometers there was a more elaborate instrument made by Unicam Instruments (Cambridge) Ltd. which has a quartz prism and chopped beam. Alternative detectors are a lead sulphide cell and a photomultiplier. The flame burns either propane or acetylene. An interesting self-balancing colorimeter using a graded interference filter and grey wedge is made by Joyce, Loebl and Co. Ltd.

Infra-red apparatus. A new detecting substance, indium antimonide, is sensitive up to about 7·5 μ when used as photoconductive or photoelectromagnetic element. The material is purified by zone melting and then grown into a single crystal from which thin sections are prepared. Pieces measuring, for example, 10 mm × 1 mm × 10 μ are mounted on a support and have leads soldered on. As the material is stable no window problems are met; the element forms its own slit by virtue of its shape. The Radar Research Establishment showed how it was possible to monitor and control an infra-red source by balancing the output from two indium antimonide detectors receiving radiation from the long and short wavelength skirts of the emission band. If then a third element is used at a selected wavelength for measurements the readings are free from errors due to drift of the source emission. The response time is so short that it is difficult to measure. The material has a high transmittance for infra-red up to a limit set by the electron density, hence it is possible to prepare it for use as cut-off filter. By making *p*- and *n*-type boundaries it can be used as a photovoltaic element sensitive up to about 5 μ. Both the Radar Research Establishment and the Services Experimental Research Laboratory had demonstrated of these effects, and the latter showed some allied materials, such as indium arsenide and cadmium telluride which have interesting properties. The Plessey Co. Ltd. make an indium antimonide cell for infra-red detection; they also showed an application of the material to measurement of magnetic field; this can be done using either the Hall effect (for lower fields) or the dependence of resistance upon the field (for higher fields).

Windows and lenses for infra-red work can be made of sapphire (Al_2O_3) (shown by Salford Electrical Instruments Ltd.) or arsenic trisulphide (As_2S_3) shown by Barr and Stroud Ltd.

Infra-red spectrometers operating up to 25 μ were shown by Sir Howard Grubb, Parsons and Co. Ltd.; these use gratings and a cam-operated slit to maintain constant energy. Mervyn Instruments Ltd. in their spectrometer use a continuously adjustable cam which can be used to correct for absorption in the sample cells as well as for source and detector variation. An attachment to the Hilger and Watts Ltd. instrument uses reflecting microscopes to focus each of the beams on to small areas equal to 1/10 of that of the source so that the infra-red absorption of fibres can be examined. There is also an attachment for measuring the reflectance of samples in comparison with that of a standard.

Various infra-red gas analysers were shown (Infra Red Development Co. Ltd.; Sir Howard Grubb, Parsons and Co. Ltd.). The outputs from these can be recorded, with a response time of about 0·1 s. Use of absorption of infra-red by a gas such as nitrous oxide is made the basis of a leak rate measurement in an apparatus made by the Infra Red Development Co. Ltd.

Interference filters and reflecting layers. Advances in the technique of production of interference filters enables the pass bandwidth to be made narrower. (Filters are prepared by Barr and Stroud Ltd. and Sir Howard Grubb, Parsons Ltd.) Graded filters for selection of a particular wavelength in the visible region can be prepared but may need a gelatine filter to remove the recurrent peak.

To control accurately the deposition of films the evaporation apparatus is made with a test source emitting light of slightly different wavelengths which are used to view the specimen alternately by means of a rotating shutter. By building up the layer until zero a.c. output is produced as the shutter rotates the required condition of maximum transmission at the mean wavelength of the test sources is ensured. This device was developed by Manchester University and the National Research Development Corporation. Maximum error is as low as ½%. Sputtered oxide films of high resistance to wear and good reflectance are obtained in an apparatus made by Edwards High Vacuum Ltd. Vacuum evaporating plant was shown by the latter firm and by Metropolitan-Vickers Electrical Co. Ltd.

Lamps. Philips Electrical Ltd. showed a useful small hydrogen lamp which provides an ultra-violet source for spectroscopy. Mercury vapour discharge lamps included a 125 W model without an outer glass envelope surrounding the quartz and a low voltage tube for production of small concentrations of ozone. An infra-red lamp and a phosphor-coated ultra-violet source from which visible radiation was removed by cobalt glass will find many applications in the laboratory, for example the latter in viewing and developing certain chromatograms. Ferranti Ltd. showed a selection of light sources with rare gas fillings.

Microscopy. An unconventional form of microscope in which the optical path is reflected twice through 90° permits construction of a small instrument which is readily portable. Normal lenses are used (McArthur Microscopes Ltd.). The National Research Development Corporation showed a surface contact microscope in which illumination *via* the glass of the face of a 60° prism at more than the critical angle furnishes a dark field except where an object is in intimate contact with the glass. Here scattering occurs and that surface of the object adjacent to the glass is made visible. Living cells in a suspension can be examined in this way. A microscope with interchangeable magnification (by rotating a cylinder) and with constant focus and working distance (3·75 in.) is under development by Cooke, Troughton and Simms Ltd. It will use a single objective. A microscope and camera for investigation of surface defects of depths from 0·0005–0·01 in. is made by Hilger and Watts Ltd.

Microwaves. Oscillators for generation of microwaves include travelling wave and backward wave tubes (Mullard Ltd.; General Electric Co. Ltd.). The Services Electronic Research Laboratory showed a pulsed magnetron operating on 3·8 mm. Power amplifier klystrons for *X* and *S* bands (Ferranti Ltd., Mullard Ltd., Metropolitan-Vickers Electrical Co. Ltd.) can be used in linear accelerators as an alternative to the magnetron. Linear accelerators were shown by Philips Electrical Ltd. and Mullard Ltd.

An interesting use of an atomic resonance of caesium at about 9192·6 Mc/s to provide frequency stability to 1 part in 10^9 is made in a Royal Aircraft Establishment apparatus. A beam of caesium atoms is passed through a magnetic field to remove unwanted energies and introduce a deflexion depending on magnetic moment. The beam is then passed through a r.f. field in a resonant cavity. Some atoms are excited by the field and this reverses their magnetic moment. The current reaching a collector after passage through a further magnetic field depends on the proportion of excited atoms and can be used to control the oscillator frequency. Ferrites can be inserted in waveguides to make T–R switches and magnetically operated switches (Plessey Co. Ltd.). Ferrite slabs in a magnetic field will provide a non-reciprocal transmission with respective losses of 0·8 dB and 12 dB for *X* band radiation (Admiralty Signal and Radar Establishment).

Apparatus for millimicrosecond pulses. Amplifiers and oscilloscopes for very short pulses are being made. The amplifier due to E.M.I. Electronics Ltd. is of the distributed type; the grids and anodes of a series of valves operating in parallel are set at intervals along two delay lines to form the capacitative elements. A pulse applied to the grid line travels down it and sets up a growing pulse in the anode line so that the output is summed but appears across the capacity of only one valve. A monitor for pulses was shown by Mullard Ltd.; and a pulse test set including source and oscilloscope by Cossor Instruments Ltd. and pulse generators by Fleming Radio Ltd. and Wayne Kerr Laboratories Ltd.

Miscellaneous materials. A series of heavy glasses for windows in nuclear apparatus are made by Chance Brothers Ltd. Densities up to 6·7 are attained and some varieties are stabilized against discoloration. Heavy glass blocks are also produced for γ-ray spectroscopy. The energy dissipated by γ or β radiation within the block gives a proportional amount of Cerenkov light which can be measured with a photomultiplier (Chance Bros. Ltd. and Optical Works Ltd.).

Tubes, sheets, and rods of the rarer metals (zirconium, beryllium, niobium, titanium, tantalum) were shown by Murex Ltd. and Accles and Pollock Ltd. The latter Company makes a variety of composite and multibore tubes including such pairs as steel and paxolin; also flexible tubes and helically finned tubes for heat exchangers.

Barium titanate strips have been used to operate relays by the General Electric Co. Ltd. These relays require practically no standing current in either open or closed states; they can be made the basis of electromechanical oscillators and might be adapted to provide a constant low frequency source, e.g. in conjunction with a tuning fork.

Photography. The Courtney–Pratt high-speed camera was shown by J. Langham Thompson Ltd. The camera operates by moving an aperture across the aperture plane of the main lens system and collecting picture elements by means of a multi-lenticular plate having 80 000 lenslets. As the size of the elements is small compared with their spacing it is possible to record a series of elements (about 300) side by side while the aperture moves. With the aperture movement taking 2–10 msec, speeds of up to 150 000 pictures per second are obtained. The events so photographed can be played back at reduced speed. A film camera taking up to 275 frames/s is made by W. Vinten Ltd. and a high-speed drum camera for oscillograph recording at up to 2500 in./s is made by Southern Instruments Ltd.

For photography of cathode-ray tube traces the self-processing Polaroid material is now available (J. Langham Thompson Ltd.). Eight exposures per film are provided and development of a positive record takes 1 min.

Cinema-Television Ltd. demonstrated a photographic printing device in which an automatic adjustment of exposure to the local density is applied. This produces positives free from blur and is admirable for such applications as aerial photographs and X-ray exposures. Use is made of a flying spot scan and the spot brightness is controlled by the rate change density of the negative.

Physiological apparatus. Continuous records of the content of carbon dioxide or other infra-red absorbing gas are given in apparatus made by the Infra Red Development Co. and by Sir Howard Grubb, Parsons Ltd. Alternatively, the velocity of sound is used to find the carbon dioxide content (Dr. Stott, Medical Research Council; Electronic Instruments Ltd.). Measurement of the total volume of expired is possible with an integrating Wolff type flowmeter made J. Langham Thompson Ltd. under a National Research velopment Corporation licence. The diaphragm of the vmeter controls the speed of a motor whose rotation responds to the volume expired. Arrangement for autotic periodic sampling of the gas is provided.

portable transistorized electrocardiograph and recorder being developed by Siemens–Ediswan Research Laboraies, the instrument has a 2·5 s time constant, 2 mV/cm sitivity on the recording paper and a discrimination ratio 100/1. The hot wire stylus makes a very fine trace on the ording paper.

modification to a centrifuge head which permits washing material (red cells) during spinning greatly reduces the time ded to remove extraneous substances (shown by the tional Institute for Medical Research).

new blood cell counter was shown by Evans Electroenium Ltd. in which 0·2 mm^3 of diluted blood is used. e cells contained in this volume are drawn into line by uid flow and counted as they approach a jet; 5000 cells counted in 10 s with 3% accuracy. Maurice's ophthalmic iometer was shown by the National Research Development rporation. In this instrument the force needed to cause mm indentation of the cornea is measured.

Rectifiers. Rectifiers giving more current from smaller lk are obtained by improvements in heat dissipation. ctifiers are embedded in loaded resin (Salford Instruments d.) or provided with edge cooling (Westinghouse Brake d Signal Co. Ltd.). Heavy duty rectifiers made with silicon germanium were shown by General Electric Co. Ltd., The essey Co. Ltd., and Ferranti Ltd. Westinghouse have proced a small selenium diode with extra high reverse resistance 0 MΩ) and 10 kΩ forward resistance. With only 7 pF pacity it should find many applications. The same company ve improved the copper oxide rectifier to reduce reverse rrent creep and allow higher input per element.

Scintillation counting. New materials to give improved ht output from scintillators are available (Nash and ompson Ltd., Ekco Electronics Ltd.). Some of these are pplied in packaged form by Nash and Thompson Ltd.; e material can be dissolved in a given volume of hydrorbon solvent and is then ready for use. For counting weak itters the samples can be injected into a gel containing ssolved phosphor or brought into solution, if necessary by e of methanol. Mountings for scintillation counters in ich the tube is protected during the introduction of samples her by a shield or by an h.t. switch were shown by Panax uipment Ltd., Mervyn Instruments Ltd. and Ekco Eleconics Ltd. Various forms of scintillation head were also own by Fleming Radio Ltd., Philips Electrical Ltd. and rndept Ltd. The two latter showed heads with directional operties suitable for locating active sources.

Storage of information and computers. Miniature ferrite res (Plessey Co. Ltd., Mullard Ltd., Fortiphone Ltd.) n be used in storage circuits. Alternatively a drilled ferrite ock with windings in each cell can be employed (Standard lephones and Cables Ltd.) The units are operated along th transistors. An electrostatic store, using polarized rium titanate with some 100 elements/cm^2 was shown by essey Co. Ltd. Magnetic drum storage was used in exhibits Ferranti Ltd. and Siemens-Ediswan Research Laboratories. n apparatus for recording and analysing data on magnetic pe is made by Mervyn Instruments Ltd.

Mullard Ltd. showed how the variation with current of e inductance of a ferrite cored coil could be used for proction of a "flip-flop" circuit and for storage. With a small alternating e.m.f. fed in to a capacity-ferrite core circuit the L and C are so chosen that it is non-resonant. Increase of the e.m.f. leads to higher current which eventually reduces the inductance; this change is arranged to lead to resonance. In this way the circuit has two stable states, one with low current and one with high current. If a pair of such circuits are fed through a common impedance and one is already resonant, a trigger pulse applied to each can only affect the non-resonant one; current is then diverted from the originally resonant one which passes to the quiescent state.

A computer for multiplication of rev/min and a displacement, as needed, for example, in engine output measurement, as made by Nash and Thompson Ltd.

Transistors. So many transistors were shown that it is impossible to give particular details. They have been applied to amplifiers, oscillators and information storage systems. Firms making them include General Electric Co. Ltd., Ferranti Ltd., British Thomson-Houston Co. Ltd., Mullard Ltd., W. G. Pye and Co. Ltd., Edison Swan Co. Ltd.

Vacuum apparatus. Edwards High Vacuum Ltd. displayed a selection of pumps, valves and pressure measuring devices. A diffusion pump with cooled ring just below the jet has improved efficiency. A form of dip stick for liquid air can be made from a carbon resistor carrying current; the high temperature coefficient of resistance leads to a large resistance change between immersed and not immersed conditions. Another level indicator used a tantalum wire which becomes superconducting when immersed. There was an electromagnetically operated sluice type valve for isolating the vacuum system and admitting air to the pumps. A porous ceramic filter for removing oil mist, sputtering and shadow casting equipment was exhibited. Metropolitan-Vickers Electrical Co. Ltd. showed pumps, valves and evaporating plant. For leak detection Metropolitan-Vickers make a small mass spectrometer. A pressure gauge with interchangeable heads, namely, cold and hot ionization gauges, and an Omegatron miniature mass spectrometer is made by Elliott Bros. (London) Ltd. A new electrode arrangement for the Bayard Alpert ionization gauge (Mullard Ltd.) uses a fine wire as ion collector; the reduced area gives rise to fewer secondary electrons as a result of X-irradiation so it will operate down to much lower pressures than the usual form. The gauge is also used as an ion pump.

CRAFTSMANSHIP AND DRAUGHTSMANSHIP COMPETITION

An exhibition of the prize-winning entries in the annual Craftsmanship and Draughtsmanship Competition was set out in the entrance of the larger hall and many of the visitors stopped to inspect the items. A decline in number of entries in some classes probably reflects the change of emphasis from precision engineering to applied physics and chemistry found in exhibits generally. A copy of the judges' report and the list of the prizewinners are printed below.

Judges' Report

The general statements made by the Judges on each class are as follows:

Class I, "Scientific instruments and components." There were fewer entrants than usual in this class this year and the general standard was not quite up to that of previous years. The Senior Grade was particularly disappointing and the entries in the Junior Grade, apart from one or two excellent examples of workmanship, were capable of a good deal of improvement.

Class II, "Tools and gauges." General class of work was up to previous standards and a number of the exhibits showed a high degree of craftsmanship. There were still a few examples chosen which did not give the scope for expressing craftsmanship at the level of this Competition.

Class III, "Optical components and systems." It was very disappointing that there was only one exhibit in this Class this year but, nevertheless, the work submitted was of such a high order of accuracy, it was most certainly worthy of the First Prize.

Class IV, "Blown glass and silica ware." The entries in Class IV were of very high standard and the general skill and neatness shown by the Competitors in the specimens exhibited this year were of a much higher standard than have been seen before.

Class V, "Sections of instruments, functional scale models of scientific interest and patterns." The statement passed by the Judges for entries in Class I also applied for Class V.

Class VI, "Draughtsmanship." By limiting the number of drawings in this year's Competition to not more than two by any one entry, thereby reducing the total number of entries, the Judges were able to spend more time scrutinizing each drawing. The average standard of draughtsmanship in both Junior and Senior Grades was as high as in past years. Many points were lost by lack of proper dimensioning of parts on the drawings, which could be avoided if competitors adopted more fully the recommendations for Drafting Practice as set out in B.S. 308.

Craftsmanship and Draughtsmanship Competition

PRIZE LIST

Scientific instruments and components (Junior grade)

First prize: B. A. Wallman (Cambridge Instrument Co.). Ewing's extensometer.

Second prize: E. Howes (Standard Telephones and Cables Ltd.). Ratchet feed, etc.

Third prize: W. Bicknell (Mullard Equipment Ltd.). Coil wave-winding machine.

Honourable mention: B. D. Cummings (Standard Telephones and Cables Ltd.). Rotary motion drive mechanism.

Scientific instruments and components (Senior grade)

First prize (shared): J. E. Bromley (Marconi's Wireless Telegraph Co. Ltd.). Part of corrector mechanism of D.F. loop. C. F. Morgan (Marconi's Wireless Telegraph Co. Ltd.). Dial indicator.

Third prize: D. G. Gittings (Radar Research Establishment). Four probe machine.

Honourable mention: A. D. Pons (Standard Telephones and Cables Ltd.). Automatic transfer mechanism.

Tools and gauges (Junior grade)

First prize: D. G. Pinnock (Services Electronics Research Laboratory). Gear tooth vernier.

Second prize: M. P. Try (A.I.D. Laboratories, Ministry of Supply). Self-adjusting vice.

Third prize: R. G. Prime (Standard Telephones and Cables Ltd.). Vernier height gauge.

Honourable mention: R. Lane (Mullard Equipment Ltd.). Sine table and vice. J. R. Ibbott (E.M.I. Electronics Ltd.). A nibbling machine.

Tools and gauges (Senior grade)

First prize: M. N. Buckingham (Services Electronics Research Laboratory). Precision off-set boring head.

Second prize: A. Money (Services Electronics Research Laboratory). Watchmaker's lathe.

Third prize: A. De Banks (E.M.I. Electronics Ltd.). Riveting squeezer for hand riveting.

Honourable mention: L. A. Harwood (A.I.D. Laboratories, Ministry of Supply). Combination sine centres and sine bar. P. F. Lucas (Standard Telephones and Cables Ltd.). Compound sine plate. E. J. Brazier (Mullard Ltd.). Adjustable angle plate. D. R. Searle (Elliott Bros. Ltd.). Jewel setting tool.

Optical components and systems

First prize: M. L. Hammond (National Physical Laboratory). Spherical and negative hemispherical glass test gauges.

Blown-glass and silica ware

First prize: M. H. Williams (General Electric Co. Ltd.). Three stage pump.

Second prize: K. R. Wolfe (British Thomson-Houston Co. Ltd.). Double stage mercury diffusion pump.

Third prize: A. J. Jones (General Electric Co. Ltd.). Multi-surface condenser.

Sections of instruments, functional scale models of scientific interest and patterns

First prize: D. Locke (Royal Ordnance Factory, Puriton). Model of Oldham coupling and Geneva mechanism.

Second prize: C. A. Bulmer (Elliott Bros. Ltd.). Roller unit friction drive.

Third prize: D. N. Frakes (Standard Telephones and Cables Ltd.). 5 in. stroke hand automatic feed shaper.

Draughtsmanship (Junior grade)

First prize: R. Greer (British Thomson-Houston Co. Ltd.). Motor barring gear for turbine.

Second prize: J. E. Wicks (E.M.I. Electronics Ltd.). Detail drawings and assembly drawing of camera assembly.

Third prize: C. Samms (Marconi's Wireless Telegraph Co., Ltd.). Standing wave indicator.

Draughtsmanship (Senior grade)

First prize: S. Barbour (British Thomson-Houston Co. Ltd.). Main governor and oil pump for turbo generator.

Second prize: T. M. Lawmon (E.M.I. Electronics Ltd.). Assembly and details of centrifuge.

Third prize: J. N. Birch (British Thomson-Houston Co. Ltd.). Details and assembly drawings of a bearing drive gear box.

Honourable mention: J. N. Fallon (E.M.I. Electronics Ltd.). General arrangement drawing and details of gear box.

Silvanus P. Thompson Prize

B. A. Wallman (Cambridge Instrument Co. Ltd.). Ewing's extensometer (exhibit and drawings).

ORIGINAL CONTRIBUTIONS

A low-frequency selective amplifier

By C. K. Battye, B.Sc., Medical School, Guy's Hospital, London, S.E.1

[*Paper first received* 19 *November, and in final form* 12 *December*, 1956]

The paper describes a selective amplifier having a frequency which is variable in steps between 1 and 1000 c/s, and a selectivity which can be set to values up to $Q = 100$. The amplifier is d.c. coupled and employs a twin-T net, shunted by a capacitor, as a selective net in the negative feedback line.

the study of electrical potentials arising in biological stems, it is frequently of advantage to have a frequency ective circuit adjustable to frequencies between 0·1 and 00 c/s.(1–3) It is seldom necessary to have a continuously riable centre frequency but often desirable to be able to just the selectivity of the circuit. As commercial instru- nts which would maintain their performance at frequencies low as 1 c/s did not appear to be available, the design of instrument to cover the range 1–1000 c/s, and which could, necessary, be extended below 1 c/s, was undertaken.

BASIC CIRCUIT

A feedback amplifier having d.c. couplings and employing esistance-capacitance null network in the negative feedback e seemed to offer many advantages over electromechanical tems and had been used successfully by previous workers. blished circuits using this system with a single valve plifier and a twin-T net as the null network, either have or selectivity or employ a method in which the twin-T work is slightly unbalanced in such a way that a small ount of positive feedback occurs at resonance, giving a Q about 20.(4) However, this method of increasing Q gives or stability for highly selective circuits as these are fully ject to changes in valve parameters and supply voltages. erefore it was thought desirable to use a multi-valve plifier with a high forward gain and some overall negative dback even at the null frequency of the selective net.

t can be shown that if a symmetrical twin-T net is included the feedback line of such an amplifier of gain A the uivalent Q of the circuit is $A/4$.(5) The selectivity can refore be varied by altering the value of the amplifier n, which can be done in one of two ways. Either the ward gain (A) of the amplifier can be varied, or the amount additional negative feedback allowed to remain at onance when the null network is operating, can be varied. latter method was chosen as it maintains a higher loop n for low selectivity settings and it avoids the difficulty of n adjustment in the d.c. feedback amplifier.

n alternative method of altering the effective Q, involving the adjustment of the shunt resistor and capacitor in the twin-T net (B and A, Fig. 1) in such a way that their product is constant,(6) was rejected as being too difficult to realize with a frequency switching system.

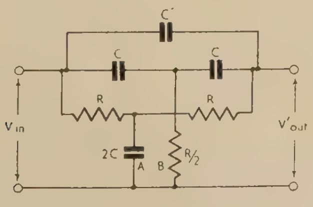

Fig. 1. Twin-T net with capacitor shunt

The frequency independent feedback, referred to above, was obtained by the placing of a by-pass impedance between the output and input terminals of the resistance-capacitance net (C' of Fig. 1).

THE TWIN-T NET WITH TOP CAPACITANCE SHUNT

The symmetrical twin-T net, unmodified by the capacitance C', has zero transmission between input and output terminals at a frequency given by(5)

$$\omega_0 = 1/RC \qquad (1)$$

When the capacitance C' is connected a corresponding frequency (ω_0') exists at which the transmission is a minimum and the output is in phase with the input. For convenience this condition will be referred to as "resonance," and ω_0' as the "resonant" frequency.

It is shown in the Appendix that when the net is driven from a zero impedance source and works into an infinite impedance load, the transmission at resonance and the resonant frequency with C' connected, become respectively:

$$\left.\begin{aligned} V'/V &= a/(a+4) \quad \text{where} \quad a = 2C'/C \\ \omega_0' &= 1/RC\sqrt{(1+a)} \end{aligned}\right\} \qquad (2)$$

It will be seen at once that the transmission of this circuit at resonance is independent of the value of R, whereas the frequency of resonance is inversely proportional to R. This suggests that the frequency of resonance can be altered by varying R, whilst the transmission, and therefore the selectivity, remain at a value set by C' and C only. In addition, the selectivity may be varied over wide limits without altering the resonant frequency by more than a few per cent.

Experiments were carried out to check these conclusions, and the results agree with calculated values to within experimental error. It will be seen from Fig. 2 that the shape of the resonance curve is not altered by changing the value of R. This enables the bandwidth for a given value of C' to be specified as a fixed proportion of the centre frequency (f_0).

The equations for the symmetrical twin-T net are symmetrical in R and C, and if C' is replaced by a resistance R', the transmission at resonance is determined by R' and R only, in an exactly similar way.

If the components of the symmetrical twin-T net differ from their nominal value, the balance condition giving zero transmission at resonance is not satisfied. In high selectivity circuits with small capacitors much difficulty may be experienced in obtaining the expected null, even with the adjustment of the components to one part in a thousand. It will be seen from equation (2) that this may be due to the presence of stray capacitance between input and output. For example, a selective amplifier system with a Q of 100, in which $R = 10^4\,\Omega$, $C = 10^{-9}$ F and $f_0 = 15$ kc/s, will have its resonant gain of 400 reduced to 330 if $C' = 1$ pF.

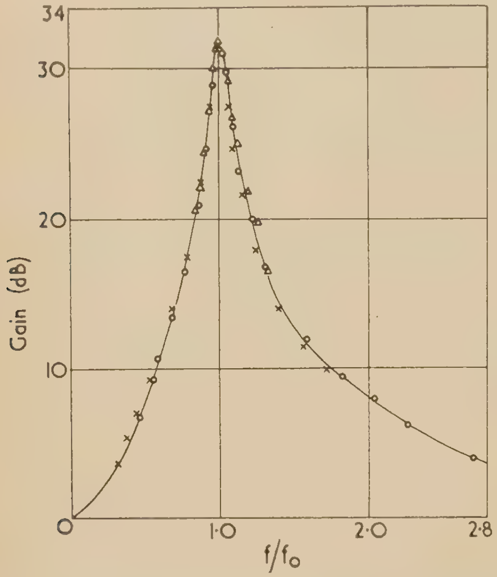

Fig. 2. Resonance curves obtained by connecting selective net ($C = 0{\cdot}01\ \mu$F, $C' = 500$ pF) in amplifier feedback line

△, $f_0 = 15$ c/s
□, $f_0 = 22$ c/s
×, $f_0 = 33$ c/s

THE AMPLIFIER

The circuit shown in Fig. 3 has a forward gain of 3500, obtained with a high μ triode and a single pentode. The selective net is inserted between cathode followers which provide a low impedance drive and high impedance termination. With a capacitor of $0{\cdot}005\ \mu$F connected from the anode of V_1 to earth the amplifier is free from self-oscillation with any degree of feedback. The d.c. levels can be set by operating the switch in the cathode circuit of V_1 and adjusting the potentiometer R_1 so that the cathode potential of V_4 becomes approximately $1{\cdot}5$ V. Stabilized power packs giving negligible ripple are required for the $+300$ and -200 V lines.

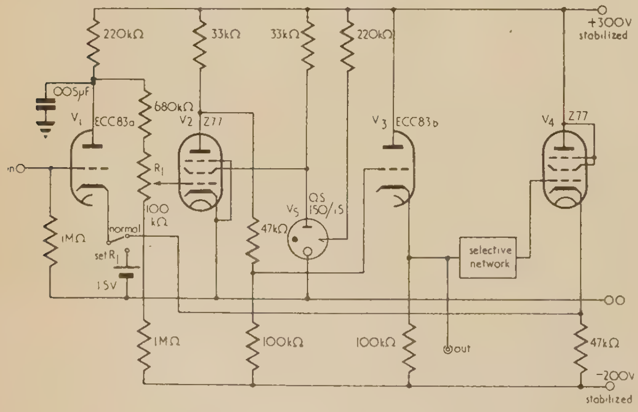

Fig. 3. Circuit of amplifier

The selective network consists of six sets of resistors and three sets of capacitors, one set of each being switched into the twin-T circuit to give the required frequency of resonance. The values of these components are given in the table, from which it will be seen that the frequencies obtainable increase approximately geometrically with an interval of $1{\cdot}5 : 1$ over a range of three decades.

Values of selective network components

C(μF)	R(MΩ)	$_0$(c/s)
0·1	1·5	1·1
	1·0	1·6
	0·68	2·3
	0·47	3·4
	0·33	4·8
	0·22	7·2
0·01	As above	As above ×10
0·001	As above	As above ×100

The appropriate by-pass capacitor is selected by a selectivit switch operating in co-ordination with the capacitor switc

ADJUSTMENT OF THE FREQUENCY SELECTIVE COMPONENTS

The components were all of 1% tolerance and were furthe adjusted to within 0·2% using a Marconi type TF936 bridg When inserted into the amplifier circuit the measured gai of the system at the resonant frequency was found to b equal to the forward gain of the amplifier, as expecte Capacitance C' was then added until sufficient transmissio was obtained in the feedback line to reduce the gain to value corresponding to the required Q. This was repeate with different values of C' to give the different selectivitie required. Values of Q up to 100 were obtained with a hig degree of constancy. Observing the decay rate of oscillatio in response to a pulsed input was found to be a convenie method of checking the Q of the system at low frequenci and high selectivities. Though in this case the lowest fr quency required was 1 c/s, there appears to be no reason wh circuits of much lower frequency could not be used to exten the frequency range.

APPENDIX

The equivalent π-circuit of Fig. 1 is given by Bolle(6) ar is shown modified by the shunt capacitance C' in Fig. 4.

The admittance of the top limb $\overline{AB}$ will be

$$Y = j\omega C' - 1\Big/\left(\frac{2}{\omega^2C^2R} + j\frac{2}{\omega C}\right) + 1/(2R + j2\omega CR^2)$$

Writing $1/CR = \omega_0$; $(\omega/\omega_0)^2 = x$; $2C'/C = a$, inverting d rationalizing:

$$= \frac{1}{Y} = A + jB =$$

$$= \frac{2R(1 - x) + j2R[x^{\frac{1}{2}}(1 - a) - x^{\frac{3}{2}}(1 + a)]}{1 + x^2(1 + a)^2 - 2x(1 + a) + a^2x}$$

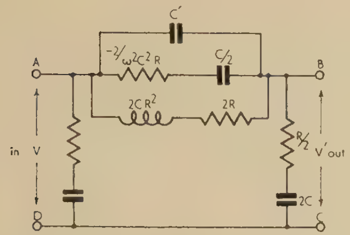

Fig. 4. Equivalent twin-π circuit

ne impedance of the output limb $\overline{BC}$ is

$$\alpha + j\beta = \frac{R}{2} - j\frac{R}{2\sqrt{x}}$$

ne transmission of the net arranged as in Fig. 5 will be

$$= \frac{\alpha + j\beta}{A + \alpha + j(B + \beta)} =$$

$$= \frac{A\alpha + B\beta + \alpha^2 + \beta^2 + j(A\beta - B\alpha)}{(A + \alpha)^2 + (B + \beta)^2} \quad (3)$$

The condition for resonance is that the imaginary part should vanish, i.e. $A\beta - B\alpha = 0$.

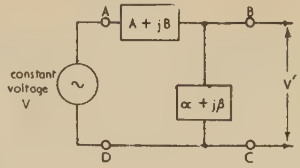

Fig. 5. Selective net schematic diagram

Hence substituting for A: B: α: β, and simplifying

$$x^2(1 + a) + ax - 1 = 0$$

from which $x = 1/(1 - a)$ or $x = -1$. The former gives the resonant frequency $\omega_0' = \frac{1}{CR}\sqrt{\left(\frac{1}{1 + a}\right)}$ and substitution of this value in equation (3) now gives the transmission at resonance: $V'/V = a/(a + 4)$.

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Design and performance of a high-efficiency laboratory electro-magnet

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[*Paper received* 22 *February*, 1957]

Major factors required in the performance of laboratory electro-magnets, namely field intensity and field homogeneity over accessible working volumes, have been achieved with moderate power consumption in an iron-clad magnet yielding power efficiencies [power efficiency ∝ (air-gap induction × air-gap)/ampere-turns] approximately 10% in excess of those obtained from similar magnets as previously reported. The magnet and support weighs $2\frac{1}{2}$ t and operates from an 18 kW d.c. supply. Pole face diameters range from 11·5 to 1·5 in. with a range of air gaps from 5 to 0·5 in. Design procedure and data are reproduced.

THE ADVANTAGES OF IRON-CLAD ELECTRO-MAGNETS

e high field induction available from this type of design s been well demonstrated by the work of Dreyfus(1) and ter.(2,3) The latter has shown(2) that the optimum ection in which non-saturable magnetic matter should be gnetized for maximum induction at a central point is nilar to the field produced by a flat cylindrical coil. A indrical yoke completely enclosing the coils is thus sug- ted, yoke leakage being reduced to a minimum. (See . 1.)

n practice, where the extent and permeability of the matter limited, the leakage from the pole piece and pole core at high inductions, becomes of paramount importance. These factors are well illustrated in the design of the Uppsala magnet.(1)

While localized homogeneity of high degree is essentially dependent upon the air-gap geometry and the physical homogeneity of the pole-piece material, some advantage for overall homogeneity is also obtained from the cylindrical symmetry of an iron-clad magnet together with the coil system. In both the magnets mentioned above(1,3) such cylindrical symmetry is essentially retained.

The high power efficiencies available from this type of design together with the modest copper and iron requirements, gives it a considerable advantage over other types of laboratory electro-magnets.

DESIGN PROCEDURE

For a required air-gap volume and magnetic induction, one can by trial and error estimate the size and geometry of the pole-piece and pole-core, knowing the saturation induction of the material used and the leakage fluxes. The latter can be estimated by either flux-plotting or electrolytic tank methods.

In order to retain the divergent form of magnetization as shown in Fig. 1, the cross-section of the pole-piece and pole-core must be carefully dimensioned; so that with the highest values of gap induction desired, the permeability of the pole-piece material should increase from a value close to unity at the extreme pole-face, to a value ~100 within a relatively short distance.

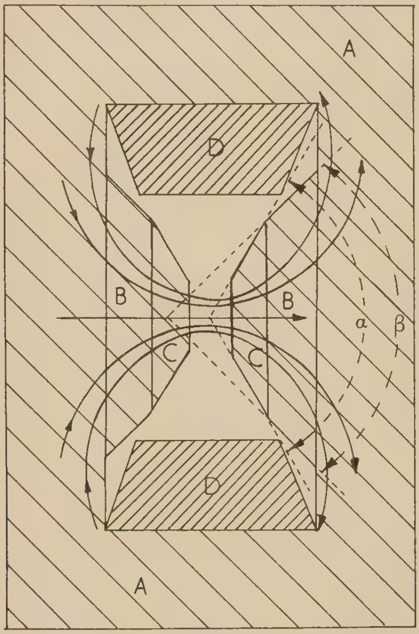


Fig. 1. Section of a cylindrical magnet showing divergent magnetization pattern required for maximum air-gap intensity

A, cylindrical yoke; *B*, pole-core; *C*, pole-piece; *D*, excitation coils; α, pole-piece angle; β, pole-core angle.

To achieve this, Dreyfus(1) (see also Snellman(4)) reports optimum angles of 120° and 90° for the pole-piece and core respectively (see Fig. 1), and on this basis quotes a formula for the ampere-turn requirements of the gap and pole-piece reluctances in terms of the base diameter of the pole-piece. Since approximately 90% of the total ampere-turn requirements is taken up by the air-gap and pole-pieces, the importance of this part of the design is evident. Up to a certain distance from the pole-face (~1·5 times the pole-face area), increase of the yoke cross-section achieves very little increase in gap induction, for a fixed gap volume. However, it is essential, especially in those portions of the yoke near the pole-pieces, i.e. the pole-cores, that the permeability be as high as possible, since saturation effects at high inductions render the yoke reluctance of increasing importance. For this reason the pole-cores should have a certain degree of conicity, while the yoke material should be made of very pure and soft iron.

Once the total ampere-turn requirements have been estimated, the coil-system can be designed. Provided the ohmic heat developed can be removed, it is best to assume a high current density as a basis, since the weight of copper for a given power input varies inversely as the square of the current density. Against this should be weighed the difficulty of stabilizing high current input where time stability of the field is important.

From the current density and ampere-turn requirements can be calculated the weight of copper and the coil dimensions.

In designing the cooling system of the coil, it should be noted that forced convection problems are difficult to solve by calculation, and unless the flow system is of particular hydro-dynamic simplicity, a preliminary experimental investigation to determine the heat-transfer coefficient between the walls of the flow system and the coolant should be made.

Knowing this coefficient and the thermal conductivities of the materials involved in the conduction of the heat from the coil to the coolant, a thermal-flow calculation can be made and the temperature of the coil hot-spot determined. Provided this is not in excess of the rated maximum temperature of the coil insulation, the coil design can be considered as satisfactory. A number of possibilities exist for the forced convection cooling of magnet coils and the literature(5,6) may be consulted.

In cases where Rose shims(7) cannot be fully utilized for correction of radial inhomogeneity in the air-gap field, or where the radial field gradient is required to be adjusted by a small amount, a distribution of the coil system toward the gap will be advantageous. The current density in those coil turns nearest the gap plane may be required to be increased above the density in those turns which are more remote.

The improvement results from the fact that the field parallel to the axis of a circular coil increases radially outwards from the coil axis provided the plane in which the radius lies is near the plane of the coil.(8)

THE N.S.W.U.T. MAGNET

This magnet was designed to provide maximum intensities and a high degree of homogeneity, in volumes provided by pole-pieces ranging from 1·5 to 11·5 in. in diameter, with air-gaps ranging from 0·5 to 5 in. The largest pole-pieces of 11·5 in. diameter are right cylinders of very pure iron. All other pole-pieces are provided with Permendur caps and are tapered to a curving profile from homogeneity considerations(9) contrary to the optimum angle of 120° as specified by Dreyfus.

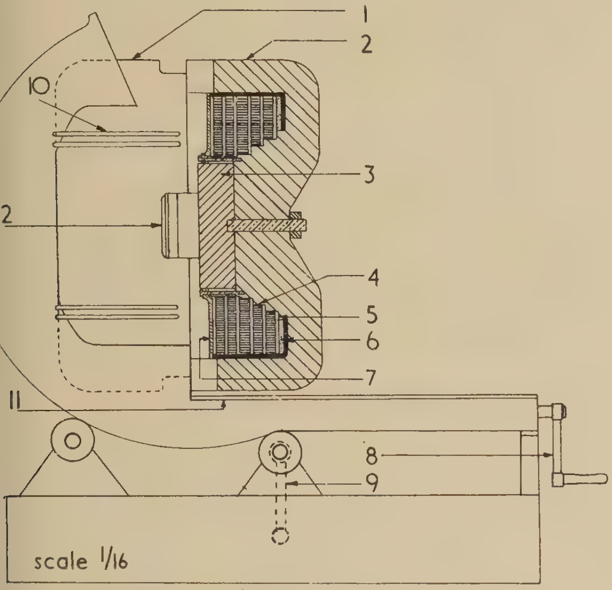
Consideration of the ideal magnetization curves of Fig. 1 with the yoke and cylindrical pole-piece geometry according to homogeneity requirements, leads to a pole-core angle of 60° rather than the Dreyfus optimum of 90°. As a partial compensation the yoke thickness was increased in this region. As will be seen, little or nothing has been lost in magnetization performance by this modification.

The yoke is split as in the Bitter magnet,(3) the dimensions being shown in Fig. 2. The weight of each yoke-half without the excitation coils and cooling system is very nearly 1t, and provides a magnetic circuit of ample cross-section. Each half was cast from iron rendered 99·3% pure in an induction furnace and then carefully annealed by allowing it to soak at a temperature of 1000° F for 10 h.

The coil system followed a standard pattern of pancakes of $\frac{3}{4}$ in. copper strip (20 gauge) interwound with glass tape and restricted from lateral movement by the soldering together of two turns at the inside and outside peripheries.

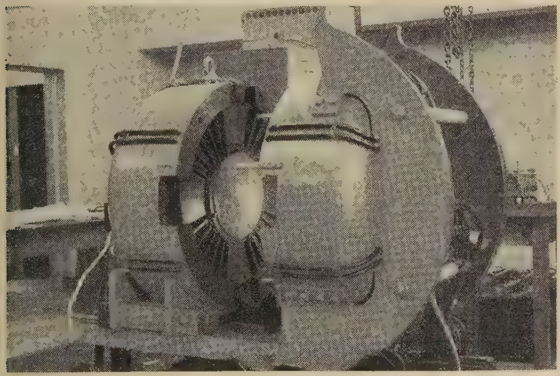
ween each two pancakes is a copper, water-cooled rinth, sheet mica being used as insulation between the cake and labyrinth. Each pair of electrical connexions esponding to a pancake is returned to a terminal block he rear of the yoke, together with the water inlet and et from each labyrinth, so that any desired series or allel arrangement of either the coil or cooling system can made. The coil system has a total of 545 turns in each e-half, a bronze pressure-plate being used as a cover for h system to ensure good thermal contact between the cakes and labyrinths.

'ariation of the air-gap is provided by spacers between the e-halves, one half rolling on a rail track as in the Bitter gnet. The whole magnet can be rotated vertically through by a manual gear (see Figs. 2 and 3).



ig. 2. Elevation of magnet showing vertical section of novable yoke-half. Rail-carriage and terminal block are not shown

), (2), fixed and movable yoke-halves; (3), cylindrical pole-iece; (4), coil pancake; (5), water-cooled labyrinth; (6), high-npedance coil; (7), pressure-plate; (8), yoke-separation ontrol; (9), vertical inclination control; (10), coolant inlet and outlet; (11), rail tracks; (12), observation apertures.



ig. 3. N.S.W.U.T. magnet showing yokes separated and 11·5 in. pole-piece

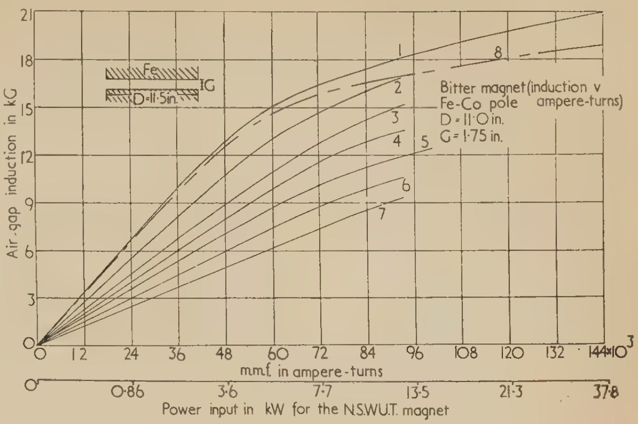


Fig. 4. Magnetization characteristics of N.S.W.U.T. magnet for 11·5 in. cylindrical poles

Curve 1, $G = 1\cdot75$ in.; curve 2, $G = 2\cdot25$ in.; curve 3, $G = 2\cdot75$ in.; curve 4, $G = 3\cdot25$ in.; curve 5, $G = 3\cdot75$ in.; curve 6, $G = 4\cdot75$ in.; curve 7, $G = 5\cdot4$ in.; curve 8, Bitter magnet (induction plotted against ampere-turns) Fe–Co pole $D = 11\cdot0$ in., $G = 1\cdot75$ in.

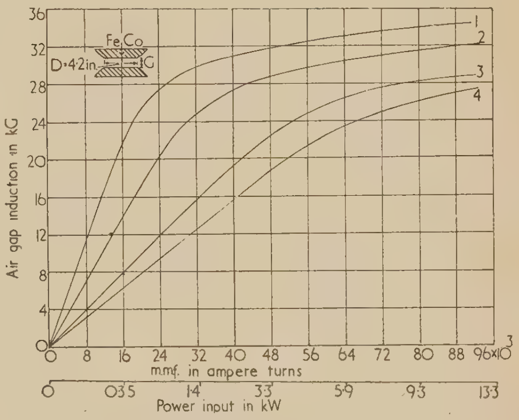


Fig. 5. Magnetization characteristics for 4·2 in. tapered poles

Curve 1, $G = 0\cdot5$ in.; curve 2, $G = 0\cdot88$ in.; curve 3 $G = 1\cdot38$ in.; curve 4, $G = 1\cdot58$ in.

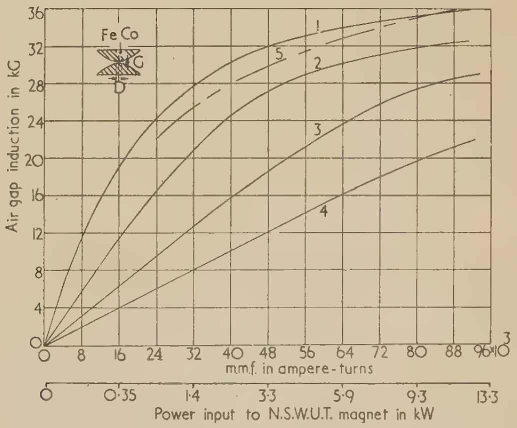


Fig. 6. Magnetization characteristics for 1·6 in. tapered poles

Curve 1, $G = 0\cdot5$ in.; curve 2, $G = 0\cdot8$ in.; curve 3, $G = 1\cdot3$ in.; curve 4, $G = 2\cdot1$ in.; curve 5, reduced Uppsala-type magnet, $D = 1\cdot6$ in.; $G = 0\cdot5$ in.

There are five sets of pole-pieces available, the magnetization characteristics of three of these being shown in Figs. 4, 5 and 6. While the magnet normally operates from an 18 kW supply, the characteristics were plotted up to higher levels in particular cases of interest, the efficiency of the cooling system being adequate to handle a 50 kW input without excessive temperature rise.

The induction measurements were made with a flip-coil and fluxmeter, and as seen from the characteristics, considerable inductions are available from all pole-pieces over quite large working volumes for very moderate power consumption.

The full inhomogeneity is not greater than 1% for all gaps and pole-pieces within a distance from the centre of about 0·5 times the pole face radius. A particular case of interest is the overall homogeneity obtainable from the 11·5 in. diameter pole-pieces. While fine adjustment of the parallelism of the pole-faces and the provision of Rose shims has not yet been made, good overall homogeneity has been achieved. Thus for a field of 7 kG and an air-gap of 1·75 in. the field is constant to within 0·05% over approximately 50% of the gap volume. Local inhomogeneity amounts to less than 0·02% over a volume of approximately 0·2 cm^3, and is substantially constant over the gap volume quoted above. All homogeneity measurements were made with a nuclear resonance probe.

COMPARISON OF PERFORMANCE WITH OTHER MAGNETS

The Uppsala and Bitter magnets weigh 33 and 2 t (U.S.) respectively. While no dimensions have been published on the latter, it and the Uppsala magnet appear to have very similar geometries to the N.S.W.U.T. magnet. It is therefore possible to calculate approximate size-ratios to compare the magnets.

Thus for the Uppsala magnet the size-ratio is

$$k_1 = (33/2)^{\frac{1}{3}} \simeq 2\cdot5$$

while for the Bitter magnet

$$k_2 = (4000/4480)^{\frac{1}{3}} \simeq 0\cdot96$$

Since k_2 is close to unity the Bitter and N.S.W.U.T. magnets may be compared directly with the magnetization characteristics. In Fig. 4 the characteristic of the Bitter magnet for 11 in. diameter Permendur pole-pieces has been plotted for an air-gap of 1·75 in. The induction of the N.S.W.U.T. magnet is approximately 10% higher at the 20 kW level and this difference increases slowly with the power level. Since no design data has been published on the Bitter magnet, it is not possible to determine whether the larger saturation effects in this magnet are due to design geometry, or lower permeability of the pole-core and yoke.

The Uppsala magnet is more difficult to compare since the pole-pieces used do not have a size factor of k_1 with respect to the N.S.W.U.T. magnet. However, two reduced characteristics have been obtained by taking air-gap dimensions k_1 times as great as in the N.S.W.U.T. magnet, reading off the induction values on the Uppsala characteristics, and plotting these against the corresponding (ampere-turns)/k_1. The air-gap is very nearly the same but the pole-face diameters are 0·5 in. below and above that of the N.S.W.U.T. magnet. An extrapolated characteristic for such an Uppsala type magnet is shown in Fig. 6 for a pole-face diameter of 1·6 in. and the same gap.

The interesting feature is the superior induction available at low-power levels with the N.S.W.U.T. magnet while saturation effects allow the Uppsala type magnet to overtake it at the 10 kW level. It is probable that the departure from the optimum pole-core and pole-piece angles in the interests of flexibility is the cause of this saturation.

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Acknowledgements are also due to Mr. K. Marsden of this School who constructed the nuclear resonance field measuring equipment used in the homogeneity determinations.

Finally it is desired to record the School's gratitude to the late Mr. J. I. Carroll of Email Pty. Ltd., Sydney, whose financial grant to the School provided for the construction of the magnet.

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agnet current stabilizer for an electron spin resonance spectrometer

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A description is given of a simple electronic stabilizer designed to supply an electromagnet with a current of 3 A, stable to one part in 3×10^4. Provision is made for the linear variation of this current with time.

INTRODUCTION

electron resonance experiments it is necessary to provide a agnetic field which is constant to a fraction of the resonance e width. This is rarely less than 0·1 G and, providing the le face area of the magnet is generous, the required field mogeneity over the sample can be obtained with a usual ctromagnet.

When working with 3 cm microwave equipment, free ctrons will absorb radiation at field strengths near 3000 G. us the stability required is of the order of one part in $\times 10^4$. Fluctuations in field resulting from changes in e temperature of the magnet will be limited to slow drifts ving to its large thermal capacity.

These are less troublesome than rapid changes, and proding the magnet is stable mechanically, it is sufficient to ep the exciting current within the required limits by the e of some feed-back system. Field stability is especially portant when the derivative of the spectrum is presented a pen recorder, as opposed to direct display on an oscillope, since some minutes may be taken to sweep through e absorption lines.

The magnet current is often several amperes, which is ther large to be controlled directly by series valves, and namo-generators with feed-back applied to the field coils ve been commonly used.(1, 2, 3) Such an arrangement has en tried in these laboratories. Phase shifts within the agnet, and between the field coils and the armature of the nerator were sufficient to cause oscillations at relatively w loop gains, making it difficult to achieve the desired ability. These difficulties have also been mentioned by randberg,(2) who has shown that they can be overcome the added complication of subsidiary feed-back loops.

1. DESCRIPTION OF STABILIZER

We have found it possible to dispense with a dynamo- nerator system by using the scheme shown in Fig. 1, which s proved both simple and satisfactory, to provide a current 3 A at 90 V. Current is obtained from the 220 V d.c. boratory supply, filtered to remove rectifier ripple, and d to the magnet by two parallel paths. One of these nsists of twelve Type 12E1 valves in parallel and carries out 1 A. The other is a high wattage resistor R_1 which n be adjusted to give a total current of about 3 A through e magnet coils. In series with the magnet is a variable sistor R_2 which is adjusted to give an input of about 3 V the direct-coupled amplifier. R_2 is of high rating to inimize heating effects. The amplifier has a gain of 2×10^4 d its output controls the current through the 12E1 valves. this means a stable feed-back loop with a gain of 300 can obtained. Voltage surges across the magnet are reduced a Metrosil surge eliminator. The operation of the abilizer can be conveniently monitored by the measurement a fraction of the voltage across R_2 with a standard potentiometer. After an initial warming up period of 30 min, fluctuations in this voltage are less than one part in 3×10^4 during an interval of 5 min. The d.c. supply shows rapid (1 s) voltage fluctuations of about 1% and is stable to 1 or 2% over several hours.

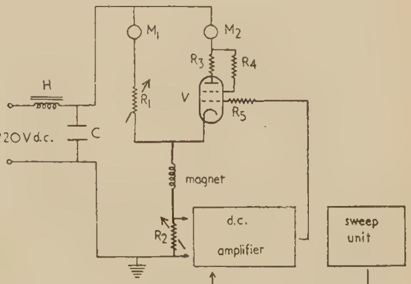

Fig. 1. Block diagram of current stabilizer

R_1 = 60 to 80 Ω 500 *W* tapped resistor
R_2 = 2 Ω 50 W variable resistor
V = 12 Type 12E1 valves in parallel, with separate grid, screen, and anode parasitic oscillation suppressors R_3, R_4, R_5
R_3, R_4 = 100 Ω 3 W wirewound
R_5 = 50 kΩ 1/2 W carbon
H = 1/2 H at 3 A
C = 150 μF 350 V d.c. wkg electrolytic
M_1, M_2 = Moving coil meters, 4 A f.s.d.
Magnet coil resistance 30 Ω

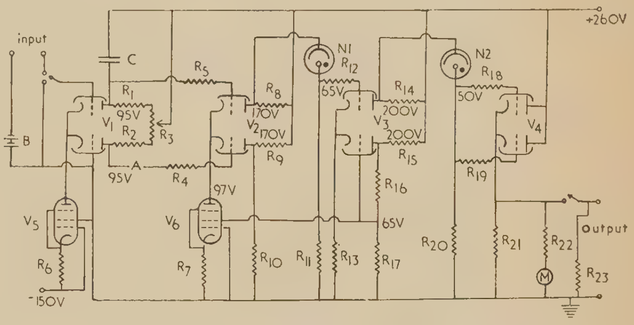

Fig. 2. Direct coupled amplifier circuit

R_1, R_2 = 200 kΩ
R_3 = 50 kΩ
R_4, R_5, R_{12}, R_{18}, R_{19} = 5 kΩ
R_6 = 1 kΩ
R_7 = 1·5 kΩ
R_8, R_{14}, R_{22} = 100 kΩ
R_9, R_{17} = 15 kΩ
R_{11}, R_{20} = 470 kΩ
R_{10}, R_{16} = 30 kΩ
R_{13} = 50 kΩ
R_{15} = 10 kΩ
R_{21}, R_{23} = 20 kΩ
All resistors are wirewound or high stability carbon
C = 0·5 μF, 350 V d.c. wkg
V_1, V_2, V_3 = 12AX7. V_4 = 12AT7
V_5, V_6 = EF86
N_1 = VR105/30
N_2 = VR150/30
B = 3 V dry battery
M = 0–1 mA meter reading 0–100 V output

Notes. The amplifier consists of three cathode coupled twin triodes V_1, V_2, and V_3, and a cathode follower output stage V_4. The latter is necessitated by the high grid current of the 12E1 valves. Pentodes are used as common cathode loads for V_1 and V_2 to give a high impedance for a moderate voltage drop, thus improving the discrimination against supply voltage fluctuations and valve ageing. The heaters of V_1 to V_4 are wired in series and draw 150 mA from a stabilized supply. The heaters of V_5 and V_6 are supplied with 6·3 V a.c. The capacitance *C* removes high frequency noise from the feedback loop.

One important source of instability in this circuit is the d.c. amplifier. Direct coupled amplifiers are prone to drifts in output voltage caused by changes in supply voltages and changes within the amplifying valves. As the amplifier is within a loop, any drift is immediately compensated by a corresponding change in magnet current. A drift of 1 mV referred to the amplifier input will cause the field to change by 1 G. The amplifier must therefore be designed to minimize drifts and must be fed from stable voltage sources.$^{(4)}$ Using the circuit shown in Fig. 2, fed from power supplies based on the circuits described by Attree,$^{(5)}$ the long term drift of the stabilizer was less than 1 in 3000 G per hour.

This performance is sufficient for most electron resonance work. To obtain greater stability any form of field stabilizer, operating on separate coils, such as one using proton resonance to give an error signal,$^{(6)}$ could be added.

2. MAGNETIC FIELD SWEEP

When the derivative of the electron resonance spectrum is to be obtained on a pen recorder, it is necessary to vary the magnetic field linearly with time over the region where resonance occurs. One convenient method of controlling the magnet current is to break the loop at some point and interpose a variable potential difference. There will be a linear relationship between this potential difference and the magnet current providing the elements of the loop between the magnet and this point are linear. The amplifier circuit is broken at the point *A*, and a variable voltage introduced from a precision wirewound potentiometer (Colvern Type CLR 8025) fed from a 60 V h.t. battery. The potentiometer is rotated at 1 rev/h by a fractional h.p. motor operating through a reduction drive.

A slipping clutch enables the magnetic field to be set manually to any desired value. The potentiometer is fitted with a scale, and a contact breaker wheel driven from the same gear train provides current pulses corresponding to the scale divisions for the operation of a marker pen on the spectrometer recorder. Resistors can be switched in series with the potentiometer to give sweep rates of 12, 6, 2 and 1 G/min.

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A method of stabilizing the specimen temperature for single crystal X-ray crystallography

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[*Paper first received* 2 *October*, 1956, *and in final form* 24 *January*, 1957]

This paper describes a method for the automatic control of the specimen temperature in a single crystal X-ray goniometer for the growth and examination of crystals down to −130° C. The principle may also be useful for other temperature ranges.

In the present instrument, nitrogen at a temperature of about −160° C is passed through a Dewar tube and directed on to the specimen. In the mouth of the Dewar tube, just above the specimen, are two heaters (*R* and *H*, see figure). One of these *H*, which is wound with platinum, acts as the temperature-sensitive element in one arm of an a.c. bridge. Its resistance determines the state of balance of the bridge, or the phase of the signal across it. This in turn controls the current flowing through the heaters by means of a phase-shift thyratron circuit and saturable reactor. This type of circuit has been fully described elsewhere,* and was originally used for the temperature control of a furnace. *A* and *C* are precision carbon resistors of the order of $10^4\,\Omega$, *A* being variable in a number of steps. *B* is a non-inductive, temperature-stable, Tarnac-wound resistor and *L* consists of a few turns of wire (having sufficient inductance to provide a signal always at the thyratrons). The amplifier is a simple two-stage unit having a gain of 2×10^4.

It is essential that the control heater *H* be made in such a way that it is sensitive to changes of temperature of the gas flowing around it. It must therefore possess very good heat transfer properties, a low thermal capacity and a uniform temperature. In the present instrument the heater consists of 5 Ω (at 20° C) of 0·004 in. diameter platinum wire which was lightly insulated and mounted non-inductively on an 0·6 g strip of 0·001 in. shim brass. This strip was coiled in a spiral and kept in shape by four fine wire dowels. The spiral was then mounted in the outlet of the Dewar tube so that the heater was distributed uniformly over the tube's cross-section.

If the heating of the cold gas were carried out solely by the control heater *H* there could be a considerable temperature gradient across the heater, leading to non-uniformity of the perature of the heater. To minimize this effect, a second ter R was mounted in the tube above H. This was a hrome heater of about 10 Ω, and, as a matter of con- ience, was connected in series with the a.c. bridge. The hrome element was mounted on a mass of copper having arge surface area (10 g of copper tubing). The relatively ge thermal capacity of this heater served both to damp rt-term temperature fluctuations of the cold gas and to nimize any "hunting" effect caused by the two heaters ng connected in series.

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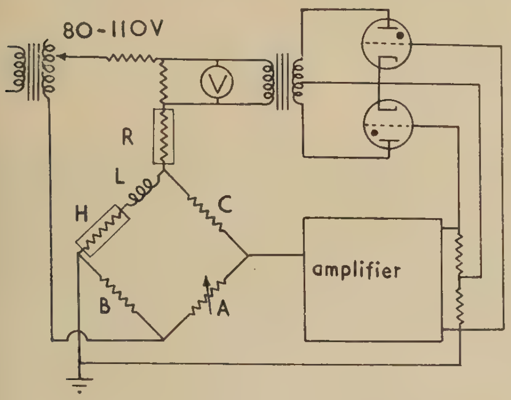
* Roberts, H. S. *Temperature: its measurement and control in science and industry*, p. 604 (Reinhold Publishing Corporation, 1941).



Circuit of the temperature control unit

t has been found possible to calibrate the bridge resistance in terms of the specimen temperature. The theoretical temperature of the control heater may be expressed approximately in terms of the equation:

$$H \propto 1/A \propto 1 - \alpha T$$

where T is the temperature in the negative direction, α is the temperature coefficient of resistivity of platinum, and H and A are the bridge resistances in the figure. Then an equation for the specimen temperature may be written in the form:

$$T = [1 - (k/A)]/\alpha'$$

where α' differs from α because of the temperature difference between the heater and the specimen. By measuring T for several different values of A and evaluating the constants α' and k, A may be calibrated in terms of specimen temperature. In operation, A is set to the desired temperature and the voltage applied to the heater circuit adjusted until the thyratron circuit is functioning satisfactorily. Because of the thermal capacity of the heaters, the final temperature is attained after several minutes.

Tests of the performance of the instrument suggest that the temperature of the specimen may be maintained to within ±0·5° C or better down to −130° C. The temperature stability is such that the growth of single crystals has been found to be a very straightforward affair. The specimen which is contained in a thin-walled tube, is frozen to a polycrystalline mass and the temperature adjusted until it starts to melt. The phase boundary remains stationary, and, providing there is a suitable temperature gradient, it is only necessary to raise the specimen slowly for crystal growth to commence. Growth rates of the order of one centimetre per two hours have been achieved.

The use of ferroelectric ceramics for vibration analysis*

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[*Paper received* 25 *January*, 1957]

The main advantage of ferroelectric ceramics of the barium titanate type for piezoelectric applications lies in their high dielectric constant, compared with the well-known single-crystalline piezoelectric materials such as quartz. Ferroelectric ceramics are used in accelerometers developed for the measurement of acceleration in vibration testing and in vibration strain gauges developed for the determination of the resonant frequencies of mechanical structures. The applications, construction and properties of these two devices are described.

1. PIEZOELECTRIC CERAMICS

ie properties and behaviour of ferroelectric crystals and ramics have been described in a recent series of review icles.(1) At high temperatures the crystal structure of rium titanate has cubic symmetry, but below the Curie int at about 120° C the structure is tetragonal, one of the les of the original cubic unit cell being longer than the her two. The crystals are ferroelectric because this structure ange is accompanied by the development in the direction the tetragonal axis of a spontaneous polarization, the nse of which can be reversed by an applied electric field. ie direction of this polarization can, in fact, be changed by suitably applied field into either direction along any one of three crystallographic axes.

Ceramics are not normally piezoelectric even if the dividual crystallites have piezoelectric properties. Because of the random orientation of the crystallites, such properties occurring in one particular crystallite will be cancelled by those occurring in opposite sense in another crystallite. For ceramics to be piezoelectric the random orientation of the crystallites must be disturbed and this is possible only in ferroelectric materials. In these materials, although the initial orientation of individual crystallites is random, the application of a sufficiently strong electric field changes the direction of polarization in many of the crystallites into that one of the various possible directions which is nearest to the field direction, and thus produces a resultant polarization in the field direction. On removal of the field, a proportion of the crystallites retain their new polarization direction; others change this direction again in order to relieve strains set up in the ceramic by the applied field. The original random orientation of the crystallites is therefore not completely restored and there is a resultant remanent polarization in the direction of the polarizing field. The piezoelectric properties of individual crystallites no longer completely compensate each other and the ceramic as a whole exhibits such properties, although not as strongly as single crystals exhibit them.

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* G.E.C. communication No. 695.

Most ferroelectric ceramics have very high dielectric constants. Small bars or disks of other piezoelectric materials, such as quartz, with low dielectric constants, have a capacitative impedance which is so high, especially at low frequencies, that the charges developed cannot conveniently be measured.

In addition to the comparatively low cost of production, a further advantage of barium titanate ceramics over most other piezoelectric materials is that their properties can be considerably modified by partial replacement of either or both of the cations by other metal ions of suitable valency, and in this way materials having more suitable properties for particular applications can be obtained. No ferroelectric ceramics have, however, yet been devised having the frequency stability or the high selectivity of quartz oscillator crystals.

2. PIEZOELECTRIC ACCELEROMETERS

If a disk of piezoelectric material is attached on one side to a surface vibrating perpendicular to its plane and on the other side to a weight, the weight produces in the disk a stress proportional to the instantaneous acceleration. During vibration this stress alternates, producing alternating charge on the surfaces of the disk. The acceleration applied to the disk can therefore be measured in terms of the output voltage developed across the disk, so that the device can be used as an accelerometer.

Often it is desirable to test a particular article to ensure that it is sufficiently robust to withstand the vibration or shock which it receives under normal operating conditions or in transit. This may involve measurement of the vibration or shock under such conditions. In order to simulate these accelerations in the laboratory the article can be tested on a vibration table, working on the same principle as a loudspeaker, or by applying mechanical shock. For such tests to be sufficiently but not unduly severe, it is necessary to measure the acceleration applied during the test. These measurements may be carried out using a piezoelectric accelerometer. Other possible applications include the measurement of shocks produced by explosions.

In the use of the accelerometer for the measurement of shock, however, it is important to bear in mind that the severity of the shock to the apparatus to be tested depends very largely on the time of application of the shock, compared with the half periods of natural frequency of the various components of the apparatus.

2.1 *Construction and calibration.* The ceramics are prepared from metallic oxides or carbonates in powder form, the major components being barium carbonate and titanium dioxide. The raw materials are milled together in the correct proportions and pressed into cylindrical blocks of convenient size. These blocks are prefired at a temperature within the range 1100–1250° C, the exact firing temperature depending on the composition of the material. During this firing the required chemical reactions occur. The prefired blocks are crushed to powder, which is milled and pressed into disks of 1·6 cm diameter. These are sintered by firing at a temperature about 150° C above the prefiring temperature. An organic binder is added before pressing and a sintering agent before final firing.

The major faces of each sintered disk are coated with a silver paste, which is fired on to produce a metallic layer. The disk is soldered to a brass base stud and an inertia weight, and the ceramic is polarized by the application of a high electric field. The upper part of the base stud, the ceramic disk and the inertia weight are all ground down together to 0·95 cm diameter and the accelerometer is protected from damp and dirt by a coating of silicone varnish.

The capacity of the accelerometer and of the cable to be used with it are separately measured. The cable is fitted to the accelerometer and if a screening can is to be used the accelerometer is mounted inside it. Two accelerometers, one in a screening can, are shown in Fig. 1. The accelerometer sensitivity is determined using a vibration table previously calibrated at the desired vibration frequency in terms of its coil current. The amplitude of vibration of the table is normally measured optically and the calibration curve is obtained by plotting the appropriate values of acceleration calculated from this amplitude and from the frequency of vibration, against the coil current.

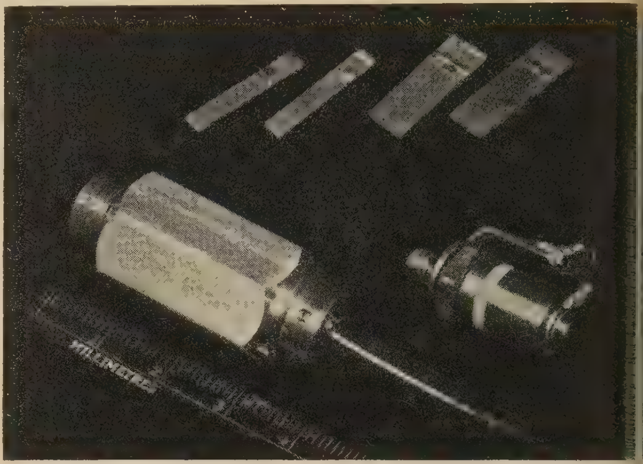


Fig. 1. Screened and unscreened accelerometer with vibration strain gauges of two different sizes

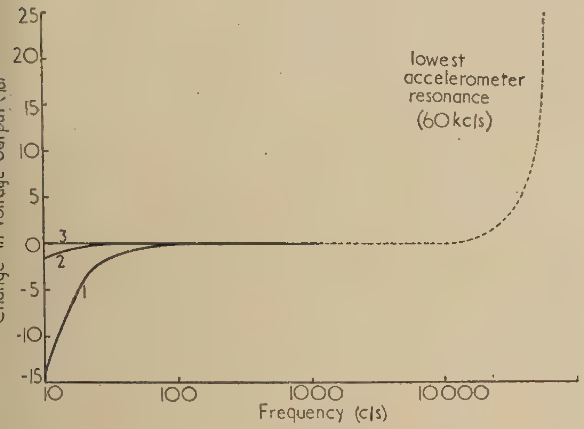
The accelerometer is mounted on the table and the coil current adjusted to give the required acceleration, which is usually 10 *g* at 80 c/s. The output voltage from the accelerometer is measured by means of a valve millivoltmeter having a cathode follower input stage of high impedance. The product of the voltage output and the total capacities of the accelerometer, cable and detector input divided by the applied acceleration gives the charge sensitivity, from which the voltage sensitivity with any desired external impedance can be calculated.

2.2 *Properties.* The properties of these accelerometers are given in the table. The accelerometer is simple in design,

Properties of accelerometers

Charge sensitivity	4·5 pC/*g* (approx.)
Self-capacity	170 pF
Capacity of lead 81 cm long	75 pF
Voltage sensitivity (with lead)	13 r.m.s. mV/*g* (approx.)
Temperature range	−40 to +100° C
Frequency range	20 to 20 000 c/s
Safe upper acceleration limit	1000 *g*
Dimensions without screening can	2·6 × 1·2 cm diameter
with screening can	3·8 × 1·8 cm diameter
Weight without screening can	11 g
with screening can	18 g

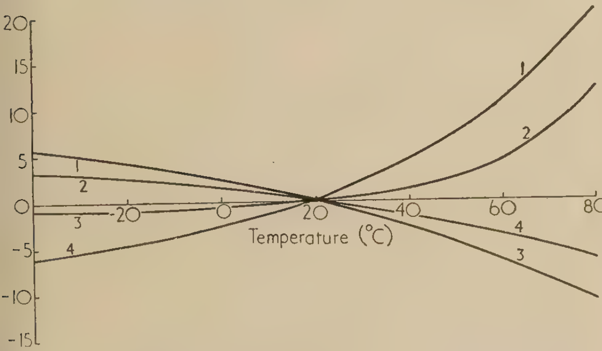
ust, of small size and weight, can be manufactured at cost and has a consistent performance over a useful ge of operating conditions. Its response is linear over working range of 0–1000 g. The first resonance of the lerometer occurs at about 60 kc/s, as shown in the uency response curve of Fig. 2. The lower limit of quency response is usually set by the input resistance of detector, and using a conventional cathode follower angement may be of the order of 10 c/s. At these fre-encies cable noise will be important and the use of a low se cable is essential.



ig. 2. Variation of accelerometer sensitivity with frequency

etector input resistances: curve (1), 100 MΩ; curve (2), 300 MΩ; curve (3), ∞.

At temperatures above 100° C partial depolarization of the amic will occur with a consequent reduction in the sensi-ty of the accelerometer. A few hours at 100° C will have le effect, but at higher temperatures the rate of depolariza-n will be larger. If the loss of sensitivity is appreciable, olarization of the ceramic will be necessary. Both the arge sensitivity and the self-capacity of the accelerometer ve a positive temperature coefficient, as shown in curves (1) d (2) of Fig. 3. These coefficients have opposite effects on temperature coefficient of voltage sensitivity, which is nged from a negative to a positive value as the external acity is increased.



ig. 3. Variation of accelerometer properties with temperature

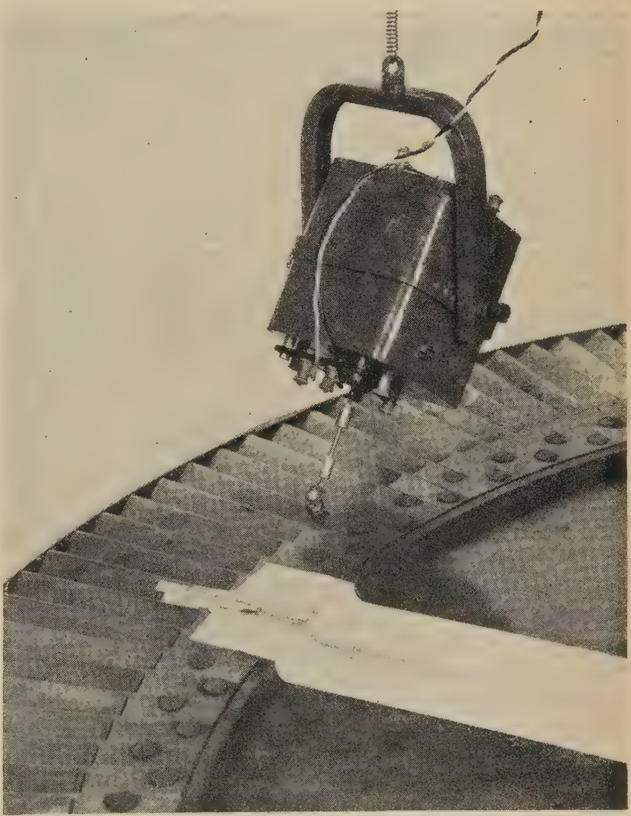
urve (1), self capacity; curve (2), charge sensitivity; curve (3), pen circuit voltage sensitivity; curve (4), voltage sensitivity with cable of 75 pF capacity.

3. VIBRATION STRAIN GAUGES

If a vibration strain gauge, consisting of a small thin bar of piezoelectric material, is attached to a surface which is experiencing strain due to vibration, the gauge will also be subject to strain and charge will be produced on its surfaces. Thus a bar of piezoelectric material can be used for the detection and analysis of vibrations in the surface to which it is attached. The gauges cannot, however, be used for the measurement of steady strain, as the charge developed will leak away.

A useful feature of these gauges is that if an alternating voltage is applied across a gauge, vibration will be produced in it and transmitted to any surface to which it is attached, the frequency of vibration being the same as that of the applied voltage. When the frequency coincides with a resonant frequency of the member to which the gauge is attached, appreciable vibration may be produced and this can be detected by a similar gauge also attached to the member and connected to some voltage sensitive device.

It is often important in mechanical structures to ensure that resonances are not excited by vibrations present under normal operating conditions, as the large alternating stresses produced in the structure might cause mechanical failure due to fatigue. The importance of avoiding resonances at certain frequencies in steam turbine blades has already been described elsewhere.(2) Other examples of mechanical structures subject to vibration, where resonances at certain frequencies are undesirable, include structural components of aeroplanes, trains, motor cars and machinery. The vibration strain



[Reproduced by courtesy of Fraser and Chalmers Engineering Works.]

Fig. 4. A vibration strain gauge and an electromagnetic exciter attached to blades in a turbine wheel

gauges are useful devices, both for measuring the frequencies at which vibration is large under normal operating conditions and for measuring natural frequencies of components, vibrations at such frequencies being excited either by mechanical shock or by an alternating voltage applied to a separate gauge. Being very small and light, these gauges permit vibration measurements to be made on components revolving at high speeds; for example, on rotating turbine wheels,(3) as well as on stationary components.

The elastic constants of materials can be obtained by using a gauge to excite resonances in a suitably shaped sample. The current supplied to the gauge will rise to a maximum at frequencies at which resonances occur, and if the damping in the specimen is low the resonance may be detected and measured using only one gauge.

3.1 *Construction.* The preparation of the ceramic is similar to that described above for accelerometer disks, except that before sintering the material is pressed into rectangular blocks of convenient size instead of disks. The sintered blocks, usually 5·2 × 2·6 × 2·0 cm, are machined to produce small, thin bars either 1·9 × 0·64 × 0·09 cm or 1·9 × 0·32 × 0·09 cm. Each bar is silvered on the two major surfaces, the electrode from the back face being extended round one edge on to a small region left bare on the front face. Thin wires are then attached on the front face to the two electrodes, so that the back face remains flat. The material is polarized using a high electric field. In Fig. 1, two gauges of each size are shown together with the accelerometers, and Fig. 4 shows a vibration strain gauge attached to a turbine blade in comparison with an electromagnetic exciter.

3.2 *Properties.* Like the accelerometer, the vibration strain gauge is very simple and can be produced economically. It requires only simple electronic equipment and gives an output of the order of 0·1 V for a strain of one part in a million, which is several hundred times the output of a typical wire resistance strain gauge. As an exciter of vibrations it is far less cumbersome and more convenient to operate up to higher frequencies than the conventional electromagnetic exciters. The latter can, of course, only be used for measurements on stationary structures.

The gauges have not so far been used where absolute strain measurements are required and so no attempt has been made to calibrate them for this purpose. Although they cannot be calibrated by static strain, it is possible to calibrate them for dynamic strain on suitable gear. The gauges can with care be removed without damage from a surface to which they have been fixed with a cellulose base cement, so that precalibration is feasible.

These gauges should not be heated above 100° C or repolarization of the ceramic will be required. The development of new materials should, however, result in an upward extension of the temperature range, increasing the field of usefulness of the gauges.

ACKNOWLEDGEMENT

The authors are indebted to Mr. P. G. E. F. Jones for hi substanital share in the basic design of the accelerometer described.

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The operation of a miniature camera by remote control

By D. E. Blackwell, M.A., Ph.D., and D. W. Dewhirst, M.A., Ph.D., The Observatories, University of Cambridge

[*Paper received* 23 *January*, 1957]

The difficulties encountered in devising a mechanism for automatically winding and releasing the shutter of a Contax camera are discussed. A suitable clutch mechanism, found to be satisfactory, is described.

In recent observational studies of the Sun, made in collaboration with Dr. A. Dollfus of the Paris Observatory, the authors have taken high resolution photographs of the solar photosphere from a manned balloon at a height of 19 000 ft.* The exposures, of 0·8 ms duration, were made by the focal plane shutter of a Contax camera. The camera was mounted on the telescope tube, and the repeated operations of winding and releasing the shutter had to be controlled from the basket of the balloon. No direct mechanical linkage between the basket and the apparatus was possible, and limitations of weight and the electrical power supply precluded the use of devices of the Magslip type. It proved to be peculiarly difficult to carry out these two operations without damaging the delicate mechanism of the camera. The successfu method here described is particularly adapted to the Contax but it would be generally applicable to all 35 mm camera with a focal plane shutter, and it is therefore of interest t place the details of the mechanism on record.

REQUIREMENTS OF THE DESIGN

In Contax models the required value of the exposure is fir set on the knob provided. The shutter is then cocked b turning this same knob in a clockwise direction until th rotation is stopped by a pin in the camera mechanism. Thi rotation also winds the film along one frame. The finger are then removed from the winding knob, and the exposur nade at leisure by depressing a button in the centre of winding knob.

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* Blackwell, D. E., Dewhirst, D. W., and Dollfus, A. *The Observatory*, **77**, p. 20 (1957).

'he problem was to carry out this apparently simple manual cedure by mechanical means; for example, by winding shutter with an electric motor and releasing it with a enoid, the sequence, duration and timing of the operations ng controlled by suitable relays and switches in the circuit. se inspection revealed that the operating mechanism must et the following requirements:

1) the winding knob on the camera must be turned through cisely one revolution to wind the shutter fully to the op" position;

2) when the shutter has been fully wound all mechanical straint must be removed from the winding knob, which is v rotated through about 5° in a counterclockwise direction the Contax mechanism. Moreover, if the shutter is eased whilst there is even a slight torque applied to the ding knob, the camera does not work smoothly and is n damaged;

3) in the event of a temporary defect in the winding chanism, the applied torque must not become large enough damage the camera by overwinding it.

THE MECHANISM

'he relevant part of the telescope is shown diagram-tically in the figure. The camera itself is mounted firmly a shaped block of Tufnol which is screwed to a base plate

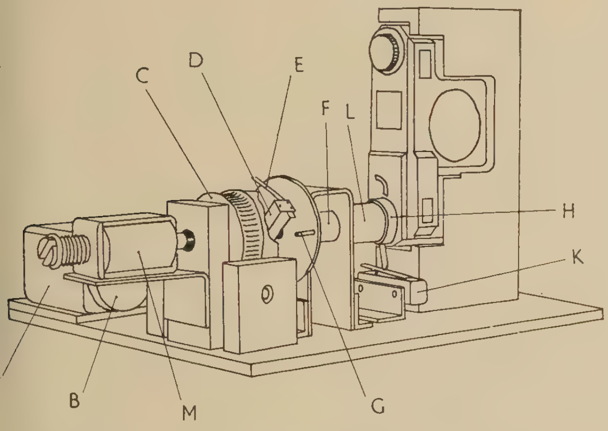

Diagram of the camera winding mechanism

Dural sheet. The winding knob is the lower one and is ned clockwise: the important components of the winding chanism are arranged along its axis of rotation. There are separate components of this main axis, the driving axle, ipled *via* a worm and wheel to the electric motor, and the ven axle, coupled to the camera winding knob. The two es are linked by a spring-and-pin clutch which is the leus of the invention.

'he driving axle. The winding mechanism is powered by 24 V d.c. instrument motor *A* of 3500 rev/min which ries on its shaft a brass flywheel *B*. The motor shaft is nected *via* a stout flexible coupling of rubber tubing to a rm (all concealed in the diagram) which drives the worm-eel *C* fixed on the driving axle, the gear ratio being 120 : 1. s short axle has soldered to it, at its end nearer the camera, rass arm *D*. At each end of this arm are mounted strips of spring steel, nearly tangential to the circle which the ends of the arm *D* describe when the axle is rotated. (The plate bearing this short axle is shown cut away, to reveal one end of this arm with its steel spring more clearly.)

The driven axle. A second short axle *F* rotates in simple bearings in two vertical brass plates. The end of this axle away from the camera carries a face plate which bears two diametrically opposed pins, one of which is shown at *G*. A split ring *H* fits rather tightly over the camera winding knob. It carries a switch arm, which is so positioned that just before the camera shutter is fully wound it depresses the lever of the microswitch *K*. The driven axle is connected to the split ring *H* (i.e. to the camera winding knob) *via* a flexible rubber coupling *L*.

The shutter of the Contax is released by pressing the button in the centre of the winding knob. The two axles described above are therefore made of tubing, and a thin central plunger runs inside them both, connecting the push solenoid *M* directly with the release button.

OPERATION

The mechanism is shown in the "ready for winding" position. The microswitch lever is already depressed, in which position the microswitch is "off" and the electric motor therefore stationary.

A contact in the control box is closed for about half a second. This short-circuits the microswitch and the motor starts. The arm *D* turns, clockwise, until the spring strips *E* come up against the pins *G*. The springs slide under the pins until the increasing frictional couple begins to turn the driven shaft, i.e. begins to wind the shutter. The switch arm clears the microswitch into the "on" position, after which the winding is completed automatically, the springs slipping further under the pins as the torque required to wind the shutter increases.

When the shutter is nearly wound the microswitch is again opened by the switch arm and the power cut off. The winding is now completed by the energy stored in the flywheel. It would then require a greatly increased torque to turn the winding knob farther (i.e. to break the camera). This the spring-and-pin clutch is unable to supply: the springs have to be pressed only a little farther under the pins to clear them completely. The arm and springs then idle on a little until the flywheel finally stops. There is now no coupling between the driving axle and the winding knob, and the shutter can be operated by energizing the solenoid momentarily. In practice, the shutter is released and immediately rewound by one operation at the control box. If by chance the motor attempts to wind an already wound shutter, no damage is done: the maximum torque which can be applied before the springs slip under the pins is adequate to wind the shutter, but quite inadequate to "overwind" it.

ADJUSTMENT

The successful operation evidently depends on the nice adjustment of (1) the microswitch position, (2) the moment of inertia of the flywheel, and (3) the strength of the spring strips *E*. Of these the last is the most important, but does not present any great difficulty: their length and precise inclination are readily adjusted and provide most of the latitude in adjustment. It is best to start with rather thin strips and replace them after trial by thicker ones until the right strength of spring is found. The maximum torque that can be transmitted by the clutch should not be appreciably greater than the winding torque, otherwise the mechanism becomes rough in its operation and the cocking knob tends to be thrown back when the clutch is disengaged. A mild-tempered steel of thickness 0·020 in. has been found suitable. The ends of the brass arm which carries the springs are rounded off to prevent stress concentrations which may cause fatigue failure. In this particular application the camera was used empty, solely for its shutter; when used with film rather stronger springs must be provided.

The apparatus has now worked satisfactorily for more than a thousand sequences of operation, over temperatures ranging from +20 to −30° C and a wide range of humidities.

ACKNOWLEDGEMENTS

The mechanism was made in the workshops of the Cambridge Observatories under the direction of Mr. R. Overhill, and the authors are grateful to the workshop staff for their interest and help. The work described is part of a special investigation financed by a Government Grant of the Royal Society.

A frequency modulated microwave spectrometer for electron resonance measurements

By A. C. Rose-Innes, M.A., D.Phil., Services Electronics Research Laboratory, Baldock, Herts

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An electron resonance spectrometer for use in the 3 cm microwave band is described. Use of a frequency modulation method allows spectra to be recorded with simple equipment, and details are given of a special technique for increasing the sensitivity. The method is especially suitable for measurements at low temperatures and for the recording of wide lines.

INTRODUCTION

A common arrangement is shown in Fig. 1 for measuring electron resonance phenomena (e.g. paramagnetic and cyclotron resonance) at microwave frequencies. The specimen is contained in a resonant cavity C terminating a waveguide and placed between the poles of an electromagnet. The coupling is so adjusted that the cavity is matched to the waveguide when the sample is not absorbing energy by electron resonance. In this case no power is reflected from the cavity. When the magnetic field is adjusted so that electron resonance takes place, the sample absorbs energy lowering the Q of the cavity. (This magnetic field, which splits the energy levels of the electrons in the crystal, will be called the "splitting field" to distinguish it from the microwave magnetic field in the cavity.) The cavity no longer matches the waveguide and some power is now reflected. Part of this reflected power is directed by the hybrid junction H to the detector, and the output of this will be a measure of the power absorbed in the sample by electron resonance.

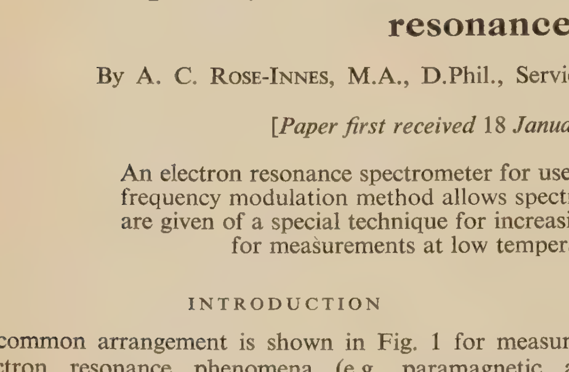

Fig. 1

In order to increase the sensitivity of the system some form of modulation of the reflected signal can be used. Two methods are commonly employed. In the "large magnetic modulation" or "l.m.m." method, the splitting field is swept to and fro through the electron resonance (usually at 50 c/s). The amplified output of the detector is fed to an oscilloscope where a picture of the electron resonance line is recorded.

In the "small magnetic modulation" or "s.m.m." method an alternating field of amplitude much smaller than the electron resonance line-width is superposed on the splitting field which is then swept slowly through the line. The amplified output of the detector is fed to a recorder which registers the derivative of the line shape.

The above methods have, however, disadvantages for certain applications. With the l.m.m. method it is not possible to examine wide electron resonance lines, because the alternating modulation field is usually obtained from subsidiary coils wound on the magnet, and it is difficult to use sweeps greater than about 100 G. Large modulation fields cause the cavity to vibrate between the magnet poles lowering the sensitivity. Furthermore, the alternating magnetic field causes eddy current heating of the cavity which may be serious if measurements are to be made at low temperatures. The maximum sensitivity obtainable with this method is probably equivalent to the paramagnetic resonance signal from 10^{14} spins with $S = \frac{1}{2}$ and with a line width of 1 G.

The s.m.m. method has higher sensitivity and it is possible to detect about 5×10^{12} spins under the above conditions. It also allows one to measure wide lines. In this method, however, the splitting field is swept slowly through the electron resonance and the microwave oscillator must be stable during this period. The Q's of the microwave cavities used are fairly high (especially at low temperatures) and therefore a high degree of frequency stability of the oscillator is required. Thus at 10 000 Mc/s the Q of the cavity is about 5000 and a frequency stability of about 1 part in 500 000 or better would be required during the time of the measurement. Frequency stabilizing systems can be used which give the necessary stability, but these are rather complicated and may involve a microwave bridge and electronic equipment as complicated as the spectrometer itself.

he frequency modulated system described in this article been devised to provide a simple system to enable wide tron resonance lines to be studied without the need for uency stabilization of the oscillator. In addition, it is licable to low temperature measurements as there is no y current heating.

THE FREQUENCY MODULATION METHOD

his method has been developed from a somewhat similar eme of Weidner and Whitmer.* Consider the bridge wn in Fig. 1 to be balanced with the klystron oscillating frequency ν_0 and the cavity tuned to resonance. No er will then be reflected up arm 3 of the hybrid junction. v let the klystron frequency be swept backward and vard over a range $\Delta\nu$. When the klystron frequency is the resonance frequency of the cavity the bridge will not balanced and there will be an output from the detector. act the output will have the form of the resonance curve he cavity (Fig. 3). In our apparatus the klystron is uency modulated by a 50 c/s alternating voltage applied he reflector, so that the output of the bridge is a series of ative peaks spaced 1/100 sec apart. When there is electron nance absorption by the specimen in the cavity, the *Q* of cavity is lowered and hence the negative peaks are not so e. These output pulses are fed to an integrating circuit ch gives a d.c. output proportional to the pulse amplitude. d.c. is fed to a pen recorder. The splitting field is varied vly and the pen records the electron resonance spectrum ne sample.

he method is not sensitive to small frequency variations he oscillator. Due to the frequency modulation of the tron, the frequency still passes through the cavity reson- e twice per cycle, so long as the drift is less than $\Delta\nu$. The ct of a small drift is only to change the distance between hbouring pulses and, since the output of the integrating uit is proportional to the height of the pulses, the output not alter unless the drift is so large that the pulses ge.

he method may be used down to the lowest temperatures, use the magnetic field is only swept once slowly through spectrum giving negligible eddy current heating.

he actual apparatus used for experiments at 10 000 Mc/s nown diagrammatically in Fig. 2. The microwaves are erated by a klystron oscillator *K* which may be frequency lulated by a 50 c/s voltage applied to the reflector. The nant cavity *C* in the Dewar vessel between the magnet s is connected to the waveguide bridge by a coaxial line consisting of two concentric thin-walled German silver s. The cavity can be tuned by means of a quartz rod rted into the cavity by a micrometer mechanism at the of the cryostat. The bridge is balanced by means of the ngers P_1 and P_2 so that, at its resonant frequency ν_0, the ty is matched to the waveguide bridge. When the tron is frequency modulated, a signal whose envelope has shape of the cavity resonance is reflected into the 3 dB rid junction D_2 and half of this signal goes up arm 3. signal is detected by a superheterodyne system consisting local oscillator klystron connected through a further directional coupler D_3. The 45 Mc/s i.f. signal lulated with the shape of the cavity resonance is amplified detected in a 5-stage "Pye-strip" television amplifier of 3 Mc/s bandwidth. This is operated in the special "saturated amplifier" manner described below.

The signal, which now has the form of negative pulses corresponding to the cavity resonance, passes through a video amplifier to the integrating circuit. This consists of an infinite impedance detector connected into a bridge circuit and adjusted so that there is no output when the specimen is not absorbing energy by electron resonance. When the amplitude of the input pulses decreases due to electron resonance lowering the *Q* of the cavity, the bridge is unbalanced and a d.c. voltage proportional to this change is fed to the pen recorder.

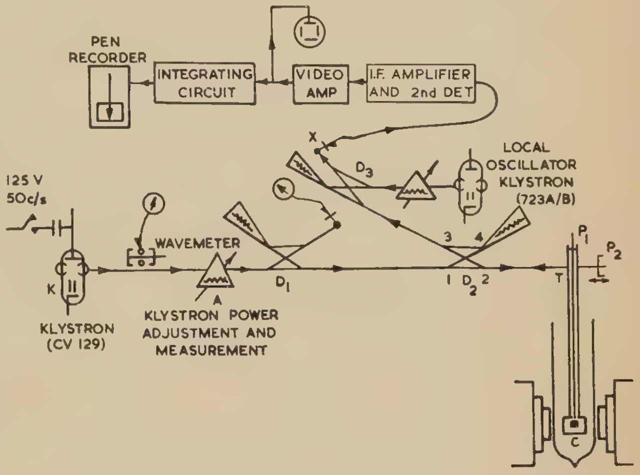
PEN RECORDER
INTEGRATING CIRCUIT
VIDEO AMP
I.F. AMPLIFIER AND 2nd DET
X
D3
LOCAL OSCILLATOR KLYSTRON (723A/B)
125 V 50c/s
WAVEMETER
K
KLYSTRON (CV 129)
A
KLYSTRON POWER ADJUSTMENT AND MEASUREMENT
D1
3
4
1
D2
2
P1
P2
T
C

Fig. 2

The electron resonance spectrum is scanned slowly by increasing the splitting field by means of a motor-driven Variac whose rectified output energizes the magnet. A spectrum is normally covered in about 3 min.

It will be seen that the spectrometer can easily be changed to the l.m.m. method of working by stopping the frequency modulation of the klystron *K* and modulating the splitting field with auxiliary a.c. coils on the magnet. The output is then observed on the oscilloscope.

THE SATURATED AMPLIFIER TECHNIQUE

The sensitivity of the f.m. method would be rather low because we only measure a small change, ΔV, of a large signal (Fig. 3). To increase the sensitivity a technique using a saturated amplifier has been developed. This is a kind of inverted "Class C" amplification, and is illustrated in Fig. 4.

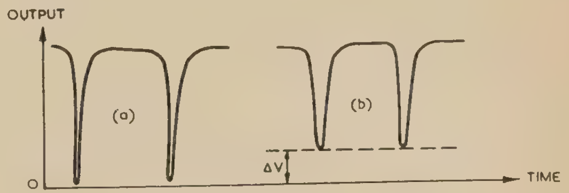

Fig. 3

Fig. 4(*a*) shows the situation in a normal Class A amplifier; a change ΔV_{in} in the input produces a change $\Delta V_{out} = G_1 \Delta V_{in}$ in the output, where G_1 is the gain of the amplifier.

Weidner, R. T., and Whitmer, C. A. *Rev. Sci. Instrum.*, 23, 5 (1952).

If we now increase the gain of the amplifier to G_2 we get the situation of Fig. 4(*b*). Here the amplitude of the input is greater than the saturation input, V_{max}, and the output is greatly distorted. However, the peaks of the negative pulses lie in the linear amplification part of the curve and the same initial change ΔV_{in} now produces an output variation $\Delta V'_{out} = G_2 \Delta V_{in}$. Hence by increasing the gain of the i.f. amplifier above saturation point it is possible to increase the sensitivity of the frequency modulation method. The amplification is limited by the fact that, if the gain is increased too much, V_{max} becomes less than the unbalance signal V_0 which occurs because it is never possible to balance the microwave bridge perfectly.

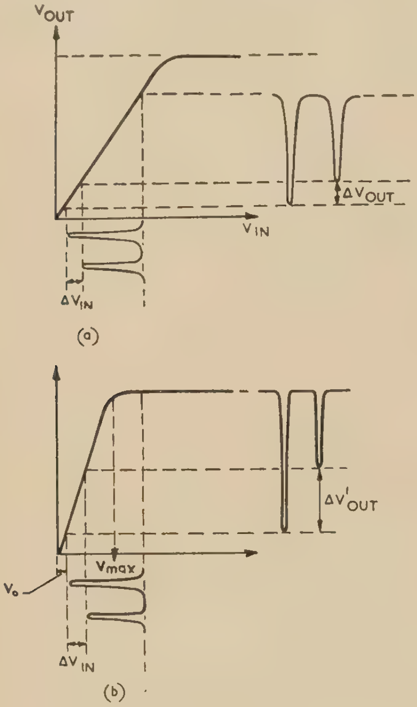

Fig. 4

In our apparatus the i.f. amplifier is used as the saturated amplifier. The gain can be varied by means of the voltage applied to the screen grids of the amplifying valves.

With this frequency modulation method the sensitivity of the system is not much less than that of the l.m.m. system. Fig. 5 shows a cyclotron resonance spectrum obtained by thi method from a sample of germanium at 4° K. The carrie were excited by means of light shone on to the specime through a quartz light guide leading into the resonant cavity A similar apparatus has been used to examine paramagneti resonance spectra at low temperatures.

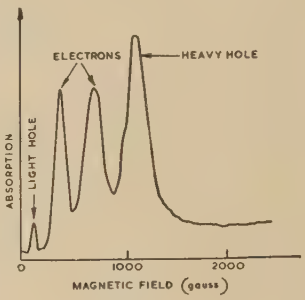

Fig. 5

The apparatus is very suitable for examining the ti dependence of the intensity of electron resonance if this not more rapid than 1/50 sec. The splitting field is set to th peak of the line and the intensity of the absorption can b recorded photographically or on the pen recorder. Fig. shows the rise and decay of the "heavy" hole resonance i germanium crystal at 4·2° K during a pulse of white light.

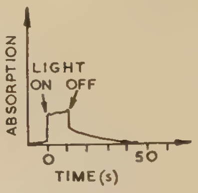

Fig. 6

ACKNOWLEDGEMENT

Acknowledgement is made to the Admiralty for permissi to publish this paper.

Note added in Proof. Since the above work was complete a paramagnetic resonance apparatus using frequency modu lation has been described by E. Lutze [*Z. angew. Phys.*, **8**, p. 6 (1956)].

A compressometer for obtaining stress-strain curves of rock specimens up to fracture

By E. R. LEEMAN, M.Sc.(Eng.), and C. GROBBELAAR, B.Sc.(Eng.), National Mechanical Engineering Research Institute, Pretoria, South Africa

[*Paper received* 6 *February*, 1957]

A compressometer is described by which the axial compressive strains occurring in a cylindrical rock specimen subjected to a linear axial compressive load in a compression test, can be read or recorded continuously up to the point of fracture of the specimen. The measuring elements are U-pieces to which wire resistance strain gauges are cemented. The U-pieces are built into the compressometer in such a way that when the specimen, to which the compressometer is attached, fractures, they fall unharmed from the compressometer. The instrument has been used to obtain the stress-strain curves of many rock specimens without its accuracy being impaired or suffering physical damage.

onducting compression tests on rock specimens a definite, inuous rate of loading up to fracture is usually specified. is desired to measure compressive strains throughout tests the strain-measuring device must be so easy to that readings can be made continuously at the rate of ing applied in the tests. Furthermore, if the strain-suring device is to remain clamped to the specimen up racture, it must be sufficiently robust to withstand the k which occurs when the specimen breaks.

he following is a description of a compressometer by h strain measurements can be made, if necessary, on a recorder up to the point of fracture of the specimen and h does not suffer damage when the specimen breaks.

DESCRIPTION OF COMPRESSOMETER

he instrument was designed to measure strains in ndrical core specimens up to about $1\frac{1}{8}$ in. diameter and th 1 in. or longer, having a gauge length of 0·625 in. onsists of two clamping rings, *A* and *B*, as shown in 1, in each of which three clamping screws are screwed.

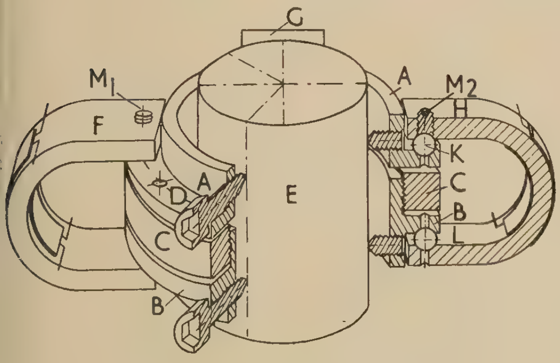

Fig. 1. A partly cross-sectioned drawing of the compressometer

ring *B* is fitted a nut *C* which screws on a thread turned ring *B*. When the rings are assembled, ring *A* rests centrically on the nut *C*, and by screwing *C*, any desired ance between the clamping screw points can be achieved. rder to ensure the same gauge length of 0·625 in. for y specimen, *C* is screwed into the necessary position and a inserted in hole *D* which is drilled through the flange of *A*, through *C* and the flange of ring *B*. By inserting a -fitting pin through this hole with the rings in contact, the gauge length of 0·625 in. between the clamping screws can be ensured simply from test to test. (In the instruments made, two locating holes similar to *D* are used and two well-fitting pins are therefore necessary.) When a test is made, the rock specimen *E* is inserted in the rings, the clamping screws tightened, the pin removed from hole *D* and *C* screwed back into contact with the flange in ring *B*. Relative movement between the two rings *A* and *C* is now possible.

The strain sensitive elements consist of the U-pieces, *F*, *G*, *H* and a fourth which is not shown in Fig. 1. To these, wire resistance strain gauges are cemented as shown. The U-pieces are placed in position and located on the rings by steel balls soldered on the flanges of the rings. The balls *K* and *L*, locating U-piece *H*, are shown in Fig. 1. An equal pre-strain is then applied to each U-piece by tightening the Allen screws M_1, M_2, etc., in the one arm of each U-piece. On applying compression to the specimen the pre-strain in the U-pieces will tend to become relieved and the relief of the U-piece pre-strain will be proportional to specimen strain, provided, of course, the stress in the U-piece has not exceeded the proportional limit of the material of which they are made. It will be noticed that any bending of the specimen is compensated for by the spacing of the four U-pieces. When the specimen fractures, the U-pieces fall off the rings and suffer no damage. The strains may be recorded on a suitable pen recorder. The wire resistance strain gauges in the U-pieces are heavily waxed as a waterproofing and general protective precaution. It has been found, however, that the layer of wax should be as thin as possible to avoid creep effects on the strain gauges. The wire strain gauges used are Huggenburger Tepic type gauges, 120 Ω resistance and 0·25 in.

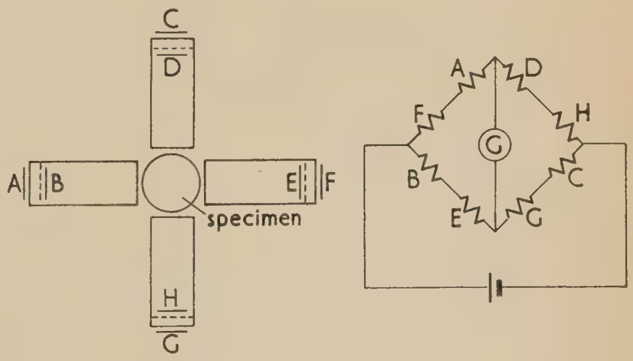

Fig. 2. The circuit diagram used in the compressometer

gauge length. They are wired into a four-arm Wheatstone bridge to give maximum sensitivity and temperature compensation, the simple circuit diagram being shown in Fig. 2 with letters showing corresponding positions.

In a later version of the instrument an improvement in sensitivity was achieved by modifying the shape of the U-pieces as shown in Fig. 3 and only using two of them instead of four. This also helped to reduce, with advantage, the clamping screw lateral loads and was sufficient to compensate for any bending effects in the specimen.

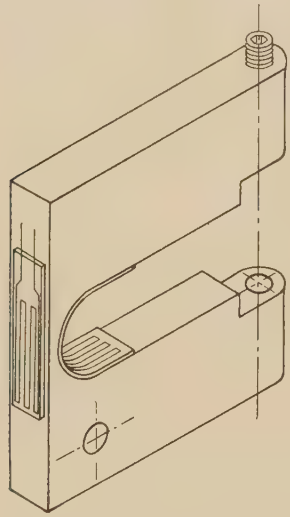

Fig. 3. Modified shape of U-piece

SENSITIVITY AND ACCURACY OF THE COMPRESSOMETER

The U-pieces were made of duralumin or brass. The calibration of the compressometer was performed by clamping it in turn to a steel, duralumin, a second steel specimen and a rock specimen to which wire resistance strain gauges had been cemented. Each was loaded in compression and the strain readings obtained from the strain gauges cemented on the specimen plotted against the compressometer readings. With a gauge factor setting of 2·00 on the Baldwin measuring bridge used, for the compressometer strain gauges, the graph obtained is shown in Fig. 4. It will be observed that by multiplying the compressometer strain reading by the facto 3 the true strain in the specimen is obtained. The accura of measurement is of the order of 4%. The calibration the instrument remained stable as is shown by the calibrat points obtained after the compressometer had been used testing sixty rock specimens to destruction.

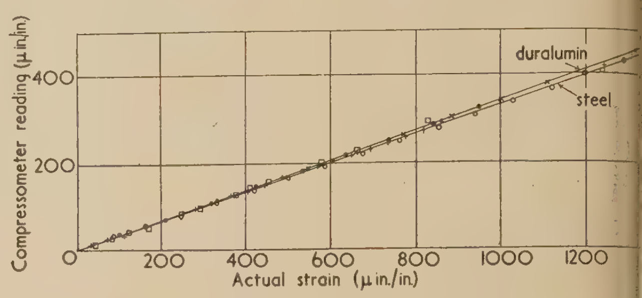

Fig. 4. Calibration of compressometer

○ rock
× duralumin
+ steel
□ steel (repeat)
● steel (after testing about sixty rock samples).

ACKNOWLEDGEMENTS

The authors wish to extend their appreciation to t Council for Scientific and Industrial Research for permiss to publish this paper.

An automatic null method recording manometer

By H. R. B. Hack,[*] B.A., Experimental Station, Cheshunt, Herts

[*Paper first received* 24 *September*, 1956, *and in final form* 14 *January*, 1957]

A brief account is given of a simple method of maintaining the position of the mercury meniscus of a manometer within less than 1 mm when pressure changes across the meniscus occur at a rate of up to 1 cm of mercury per minute. The limits of movement of the meniscus are determined by electrical contacts inserted through the manometer wall. The balancing of a pressure change across the meniscus is effected by the movement of a mercury reservoir raised or lowered by the rotation of a bobbin controlled by an electromagnetic ratchet relay. Each movement of the reservoir is recorded by an electromagnetic hammer.

A common form of mercury manometer consists of two arms connected by flexible tubing. One arm leads to a mercury reservoir, the other is a vertical tube of uniform bore. This tube may be connected to the system whose pressure it is desired to measure. If it is required to maintain this system at constant volume within specified limits, it will be necessa to maintain the mercury meniscus in the vertical tube a null position within appropriate limits depending on the bo of the tube. The meniscus will remain stationary (apart fro frictional effects) only as long as the differential pressu across it is zero. A change in this pressure differential m be balanced by suitable movement of the mercury reservo Provided that the rate of change in pressure of the system easured is such that the lag of the manometer can be cted, this change of pressure will be measured by the cal movement of the reservoir.

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[*] Now at the Glasshouse Crops Research Institute, Littlehampton, Sussex.

is the function of the present apparatus to carry out the tment of the height of the mercury reservoir automatic- and cheaply. The movement of the reservoir is made to discontinuously in steps of about 0·5 mm. Each ment is recorded by the action of an electromagnetic mer on typewriter ribbon on a moving chart.

DESCRIPTION OF APPARATUS

e null position of the mercury meniscus is determined vo platinum contacts arranged as shown at Y_1 and Y_2 g. 1. The wires are directed down the tube. They are oly pointed as recommended by the British Scientific uments Research Association for mercury switches. vertical distance apart of the platinum points was in resent apparatus approximately 1 mm.

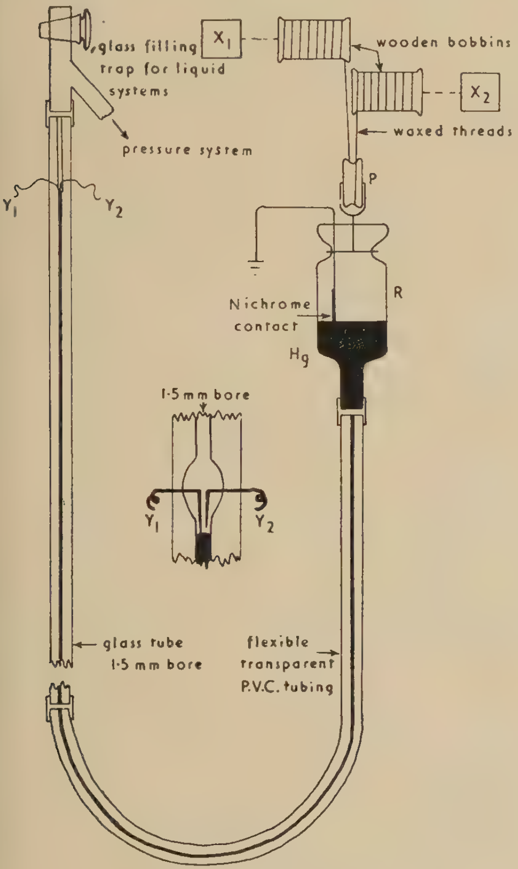

Fig. 1. Diagram of apparatus

rcury reservoir R riding on pulley-wheel P; platinum tacts (Y_1, Y_2) at null position (*enlarged inset*); ratchet relays (X_1, X_2) mechanically linked to rotate bobbins.

ıen contact is made at Y_2 or broken at Y_1 the reservoir be lowered or raised to restore the null position. The ratus also provides a record of this movement as it ·s. Contact at Y_2 (or break at Y_1) actuates, through s, a ratchet stepping mechanism X_2 (or X_1) and an omagnetic hammer X_2' (or X_1') which records the movement on a strip chart. Operation of X_1 and X_2 causes the rotation of a bobbin by about 1/100 of a revolution per impulse (depending on the number of teeth on the ratchet wheel). The bobbin rotated by X_2 unwinds and the bobbin rotated by X_1 takes up a waxed thread on which rides a pulley wheel P that supports the reservoir R. X_1 and X_2 could alternatively be the relay coils of a two-way ratchet stepping relay.

Control circuits (Fig. 2). A four-bank selector switch is used to feed a number of recorders, but for simplicity Fig. 2 shows the wiring for a single recorder only. When the wiper on bank 3 is in a position to accept a signal from Y_2 (as shown) then closure of contact Y_2 energizes relay coil A_b which causes switch A_2 to close (C_1 is normally closed) and energizes the slowly acting relay B. Relay B closes three switches:

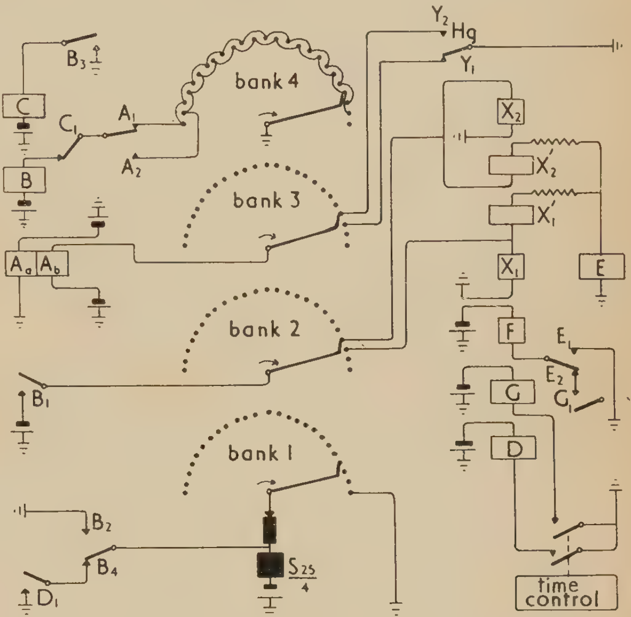

Fig. 2. Diagram of control circuits

Bank 1, self-stepping skip contact; bank 2, outgoing control selection; bank 3, incoming signal selection.

(1) B_1. When closed, electromagnet X_2 is energized to initiate the winding of the bobbin; and also the electromagnetic hammer X_2' to mark the recording paper. X_2 and X_2', in parallel, can only be actuated when Y_2 is capable of giving a signal.

(2) B_2. When closed, the uniselector S is energized, and the four ganged wipers are now ready to move on one step.

(3) B_3. When closed, this energizes relay C which now breaks switch C_1 and so cuts out relay B. The switches B_1 and B_2 now open, the hook pawls of S and X_2 are released, and by spring action each drives its ratchet wheel one step, and the hammer X_2' leaves the recording paper. The movement of S takes the wipers on to a position to accept signals from Y_1 (controlling X_1 and X_1'); that of X_2 lowers R by approximately 0·5 mm as the waxed thread unwinds.

At this stage contact Y_1 may remain closed, or it may open. If still closed, relay coil A_b remains energized, switch A_2 remains closed, but the wiper on bank 4 can now only energize relay B through A_1, which is open. Hence B is not energized and no operation takes place. If Y_1 is opened then relay B

is energized through switch A_1, which stays in its closed rest position, and the operations (1) to (3) above recur with X_1 and X_1' actuated because of the new position of the wiper on bank 2. The mercury reservoir is raised 0·5 mm, and the uniselector wipers move on to accept signals from another manometer.

Independent movement of the selector is provided by impulses from a time control box. This source can give impulses at intervals of 1, 10, 30, 60 s, 15, 30 or 60 min, as required, the impulses energizing relay D to close switch D_1. When B_2 is closed B_4 is broken thus preventing energizing of S through D.

Recording. The drive F (Fig. 2) for the drum winding the recording paper is an electromagnetically driven ratchet wheel as used to drive the bobbins. It is stepped on by the closing of the contacts G_1 when an impulse from the time control energizes relay G. Two time bases are marked by electromagnetic hammers. The step of the drum is synchronized with one of these. The other marks a longer interval. The drum is also stepped on when any one of the recording hammers, X_2', X_1', etc., comes into action. This is effected by the closing of contacts E_1 by relay E which is in series with the hammers; the breaking of E_2 disconnects the drum electromagnet from the time control so that the drum cannot be moved during receipt of a manometer reservoir movement record. The indicating marks on the recording paper are made by the action of the various hammers (X_1', X_2', etc.) on typewriter ribbon. This ribbon is moved across the recording paper by a secondary drive from the spindle of the electromagnetically driven ratchet-wheel which controls the drum. A separate recording drum has been used for a group of three manometers. The drum thus carries records from eight hammers: two give time bases and the other six are arranged in three pairs; one member of the pair marks the upward and the other the downward movement of a reservoir.

Power supplies. The specification for the relays is not critical except in the case of relay A. Relay B, however, must be slower acting than relay A which operates at about 25 ms.

It was found during 1954, when the recording apparatus was on trial in a glasshouse, that very small bubbles appeared on the surface of the mercury at the platinum–mercury contact after three or four day's run, when voltages as low as 0·6 V d.c. were used to energize relay A. This phenomenon has not yet been satisfactorily explained. However, the original relay was replaced with the sensitive moving coi relay (two coils, 100 Ω each) which was maintained biased at a potential of about 0·1 V on coil *Aa*. Its second coi *Ab* was energized at a potential of 0·2 V which was the potential across the open contacts mercury Y_1 or mercury Y_2. This system has, so far, given no trouble from bubble formation.

The other electromagnets in the system (selector switch, ratchet relays, Post Office 3000 relays) are operated at about 30 V d.c. This is taken from the mains *via* a transformer and selenium rectifiers. It was found at first that there was considerable voltage drop when the 14 Ω and 22 Ω electromagnets of the ratchet stepping switches were energized. It was decided to use separate rectifiers for sections of the circuit, i.e. one rectifier for the time control system, a second for the selector control relays, reservoir drive, electromagnets and recording hammers, and another for each recording drum drive. It is also advisable to use large reservoir capacitors across the rectifier output.

Control capacity. Using a four-bank selector switch (as shown diagrammatically in Fig. 2) having 25 contacts per bank it is possible to arrange for twelve manometers to come into action successively by suitable wiring of banks 2 and 3. Each switch (Y_1–Y_{24}) and each electromagnet (X_1–X_{24}) would then have an opportunity of acting once in one rotation of the stepping switch. Any contacts unused are slid over by means of the self-stepping mechanism of S being energized by the closing of contacts on bank 1.

The maximum rate of movement of the reservoir R depends partly on the diameter of the bobbin winding the thread. The bobbin shown in Fig. 1 (diameter about 3 cm) gives a movement of approximately 0·5 mm per step of the ratchet. The maximum possible frequency of this movement depends on the time control if impulses are fed to the selector at the rate of two per second. With the present time relations of the control relays this is independent of the activity of other manometers.

APPLICATIONS

The recording manometer has been employed for soil moisture tension measurement both in the study of non-steady state characteristics of soil moisture movement, and in the study of the lag of soil moisture tensiometers associated with water passing into the soil from an ordinary manometer as the tension rises. The results will be published elsewhere.

A thermostat using a resistance thermometer and a galvanometer–photocell amplifier

By P. M. Hu, Ph.D., A.Inst.P., and R. W. Parsons, D.Phil., Physics Department, University of Hong Kong

[*Paper received* 11 *February*, 1957]

A very simple thermostat has been constructed and tested in a water bath up to 65° C. It has proved capable of keeping the temperature constant to within ±0·005° C. A salient feature is a simple d.c. voltage amplifier, using a robust galvanometer and two photocells which are connected in adjacent arms of a Wheatstone bridge. The amplifier has a gain of 5×10^5 and is sufficiently sensitive so that circuit operation will occur if the temperature changes by 0·001° C.

ater bath, the temperature of which could be maintained in ±0·005° C of any desired temperature up to 65° C several hours, was required for use with a viscometer. apparatus described in this paper has kept the temture within these limits, and could be used for control a wide range.

he general method is similar to that used by Hutchinson, ford and White,⁽¹⁾ but the use of complicated electronic pment has been avoided. A resistance thermometer is l as the sensitive element. It is connected in one arm of Vheatstone bridge, and the out-of-balance voltage is lified with a galvanometer and two photocells. The lified voltage is applied directly to the grid of a thyratron ch controls a Post Office relay in the bath heater-circuit. complete circuit diagram is shown in Fig. 1.

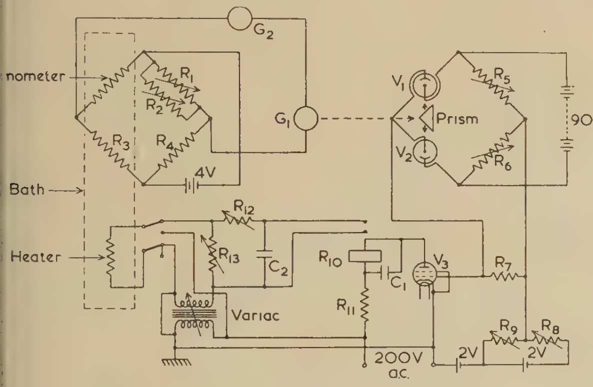

Fig. 1. Circuit diagram of thermostat

= 1–11, 110 Ω in Post Office box
= 1–11, 111 Ω decade box
= 100 Ω
= 100 Ω in Post Office box
R_6 = 10 × 10 kΩ decade boxes
= 10 MΩ
R_9 = 100–11 000 Ω decade boxes
= 10 000 Ω Post Office relay
= 10 kΩ
R_{13} = 100 Ω rheostats

G_1 = galvanometer in box
G_2 = monitor galvanometer
V_1, V_2 = CE–918 (Continental Electric Co., Illinois)
V_3 = EN91 (Mullard)
C_1 = 1 μF
C_2 = 0·25 μF

THE CONTROL DEVICE

he resistance thermometer. The resistance thermometer imilar to the type used by Dickinson and Mueller.⁽²⁾ coil of 47 s.w.g. enamelled copper wire is wound bifilarly a strip of mica 14 cm × 2·7 cm × 0·2 mm. It has a stance of 53·8 Ω at 20° C, and is insulated from its copper ith by strips of mica slightly wider than the one on which wound and approximately 0·05 mm thick, the arrangeit being illustrated in Fig. 2. The sheath is made from a ⅞ in. diameter copper tube, the wall thickness of which has been reduced to 0·3 mm for a length of 15 cm. This is flattened after the coil has been inserted until the overall thickness is between 1·1 and 1·3 mm. The lower end is then soft-soldered and the thermometer is filled with dry air.

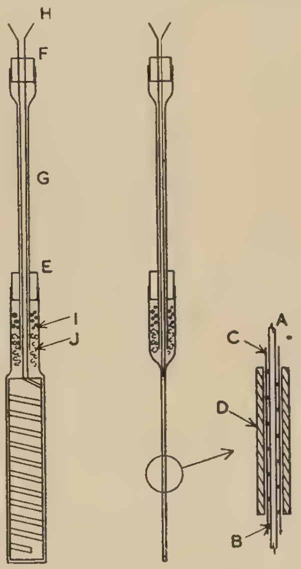

Fig. 2. The resistance thermometer

A, mica former; *B*, winding, 120 turns of 47 s.w.g. enamelled copper; *C*, 0·05 mm mica strip; *D*, copper sheath; *E*, *F*, rubber stoppers smeared with silicone grease; *G*, glass tube; *H*, leads; *I*, silica gel; *J*, glass wool.

The control bridge. The thermometer is connected to a shunted Wheatstone bridge. In an attempt to make the balance point independent of room temperature, one of the fixed arms, consisting of a Muirhead type A–70 100 Ω resistor enclosed in a thin copper tube filled with paraffin, is also immersed in the water bath. The remaining two arms of the bridge use two arms of a Post Office box, one of which is shunted by a five-decade resistance box. The plugs of the Post Office box are clean and are pushed tightly into their sockets. The resistance of the shunt is always several thousand ohms and so any variation of the resistance of the contacts in its rotary switches produces a negligible effect on the bridge.

The bridge is supplied by two 2 V lead accumulators connected in series. The out-of-balance current is passed through two Gambrell pattern 3086 reflecting galvanometers, one of which is inside a light-tight box and is used in conjunction with the photocells, while the other is outside the box and is used for monitoring. The galvanometers, which are designed for student use and are very robust, have resistances of approximately 90 Ω and current sensitivities of 10 cm/μA at a scale distance of one metre. At 60° C, a change of 0·001° C in the temperature of the resistance thermometer causes a galvanometer deflexion of 1·4 mm.

Since electrical energy is supplied to the coil of the resistance thermometer, its temperature T will exceed the bath temperature T_0. If V, the voltage applied to the bridge, changes, and if the resistances of the remaining arms remain constant, the bath temperature will alter so that T remains constant. Hutchinson and others,(1) using a thermometer of nominal resistance 2000 Ω and a bridge voltage of 80 V, had to use a stabilized power supply for their bridge in order to obtain extremely precise control of temperature. To decide whether this would be necessary in the present work, T_0 was measured with a Beckmann thermometer for several values of V between 1 and 6 V. In this interval, the graph of T_0 *versus* V^2 was linear, and it was deduced that a change of V from 4·1 to 4·0 V results in a change of less than 0·002° C in the bath temperature. Since a temperature change of this magnitude can be tolerated, lead accumulators are used to supply the bridge, as, provided they have not been freshly charged, they are sufficiently stable.

The galvanometer–photocell amplifier. One of the galvanometers in the control bridge is in a light-tight wooden box, 130 cm long, which also contains a galvanometer lamp, a right-angle prism with silvered faces, and two type CE-918 gas-filled photocells. Light is reflected from the galvanometer mirror, which has a diameter of 7 mm and focal length of 50 cm, and is incident on the prism where it is divided into two beams which fall on the cathodes of the photocells. These are mounted with their axes horizontal. The lamp has a 6 V 18 W bulb and is mounted below and behind the prism, which is 85 cm from the galvanometer.

The photocells form two adjacent arms of a Wheatstone bridge, the other two arms of which use single decade resistance boxes of magnitude 10 × 10 kΩ each. A 10 MΩ carbon resistor is connected from the junction of the photocells to the junction of the resistance boxes. The e.m.f. for the bridge is provided by a miniature 90 V battery of dry-cells.

The prism and galvanometer are adjusted so that, when no current passes, the light is approximately equally divided between the two photocells. The photocell bridge is then balanced by adjustment of one of the decade boxes. If the galvanometer is now deflected, the light incident on one photocell is increased while that on the other is decreased, and so the photocell bridge becomes unbalanced. A deflexion of 1 mm gives rise to an out-of-balance voltage of 0·9 V. In order to produce this deflexion, the out-of-balance voltage in the control bridge must be $1{\cdot}8 \times 10^{-6}$ V and so the gain of the galvanometer-photocell amplifier is $0{\cdot}9/1{\cdot}8 \times 10^{-6} = 5 \times 10^5$. The balance point of the photocell bridge is not appreciably affected by a ±10% change of either the battery voltage or the galvanometer lamp voltage; in this respect, the use of two photocells in a bridge is superior to the usual methods employing only one.(3, 4)

The trigger circuit. The voltage developed across the 10 MΩ resistor in the photocell bridge is applied to the grid of a Mullard type EN91 thyratron which, when the photocell bridge is balanced, is just biased to cut-off. The bias is obtained from accumulators, although dry-cells would probably be satisfactory; a change of 0·1 V in the e.m.f. of the bias batteries produces no measurable effect on the bath temperature. The anode is connected *via* a 10 000 Ω Post Office relay to the 200 V, a.c. supply, so that if the grid potential rises the thyratron conducts for part of each cycle and the relay closes. This controls part of the bath heater-current.

For the initial measurements, a constant-voltage transformer was used to supply the thyratron. This, however, was quite unnecessary and has been discarded. By observing the deflexion of the monitor galvanometer in the control bridge, it was concluded that a change of 10% in the voltage of the a.c. mains produces a change in the thyratron trigger-point corresponding to a change of bath temperature of the order of 10^{-4} °C.

However, the deflexion of the monitor galvanometer at the instant the relay closes does not remain constant but drifts by as much as ±1·5 mm, corresponding to a temperature change of approximately ±0·001° C, over a period of several days. This may be due to creep of the zero of the galvanometer in the box, although no comparable creep was observed in the monitor galvanometer. It seems more likely that it is due to instability of the gas-filled photocells. This drift is of no importance to the present work. However, the use of vacuum photocells in a d.c. amplifier is at present being investigated; they may offer several advantages, including greater stability.

PERFORMANCE

The thermostat was tested in a cylindrical water bath o eighteen litres capacity. This is housed in a wooden box a the sides and bottom are lagged with wood wool. The t of the bath has a double-wall Perspex lid which has holes insertion of the thermometers and stirrers. In order t maintain the temperature 35° C above room temperatu the required power input is approximately 38 W. For mo of the measurements, the room temperature was kept a 19 ± 2° C by means of electric heaters.

The resistances R_{12} and R_{13} in the bath heater-circuit a adjusted so that, depending on whether the relay is closed open, the power supplied to the bath is approximately 20 above or below that required to maintain a constant temperature. Owing to the thermal inertia of the heaters an thermometer and the backlash in the thyratron trigge circuit, the monitor galvanometer oscillates by ±1·5 m about its mean position. When this is superimposed on th long term drift, it is found that the galvanometer deflexio may vary between ±3 mm during the course of several days If this were a true measure of the bath temperature, it woul mean that the temperature does not change by more tha ±0·002° C.

However, although two adjacent arms of the control bridg are in the bath, the balance point is not completely independent of room temperature. This was verified by disconnecting the thermometer from the bridge and replacin it by a fixed resistor which was also in the bath. The bat temperature was kept approximately constant by manu operation of the switch in the heater circuit, and the roo temperature was changed by using hot-air blowers. It w found that a change of 4° C in room temperature caused th galvanometer to deflect by 7 mm. If a change such as th occurred while the thermostat was operating, the bath temperature would be changed in order to keep the contr bridge balanced. It is essential to provide different an independent methods of measuring the bath temperature an not to rely on the indications of the control bridge itsel Measurements were therefore made with a thermistor an with two Beckmann thermometers.

hermistor measurements. A Veco thermistor, type 32A1,
mounted near the centre of the bath. It was connected
Wheatstone bridge which was supplied by a single lead
mulator and the out-of-balance current was measured
a galvanometer. At 55° C, a galvanometer deflexion
cm corresponded to a temperature change of 0·004° C.
as necessary to control the bridge voltage, as a change of
013 V produced a change in resistance corresponding to a
perature change of 0·001° C. This was done by manual
stment of a resistance in series with the accumulator, and
voltage was measured with a potentiometer and potential
der. It was not allowed to vary by more than ±0·0004 V.
he galvanometer deflexion fluctuated rapidly, as the
mistor responded rapidly to change of temperature. A
rding galvanometer was not available, and so the deflexion
read at three-second intervals for four-minute periods,
the mean deflexion taken as an indication of the mean
temperature during that period. This was repeated
ral times each day, and it was found that the mean tem-
ture of the thermistor varied by less than ±0·0045° C
ing a run of several days, while during any five hours the
n temperature seldom changed by more than ±0·002° C.
uperimposed on the long-term drift was the short-term
tuation due to the regular changes in the bath heater
er, and possibly to changes in the water circulation.(1)
ing any four-minute period, the maximum fluctuation
om exceeded ±0·003° C, while for over 80% of the time
temperature was within ±0·002° C of its mean value.
seems safe to conclude that the temperature of the
mistor varied by approximately ±0·005° C during a run
several hours. The variation of temperature of a body
ose thermal capacity is much larger than that of a ther-
tor can therefore be kept well below ±0·005° C by
rting it in the bath, since, in this case, the short term
tuation is not important.

he Beckmann thermometers. A Beckmann thermometer
not respond to small, rapid changes of temperature.
wever, it was desirable to measure the long-term change
emperature by a non-electrical method, and so, as two
kmann thermometers were available, they were both
rted in the bath. Both were graduated in 1/100° C, and
observing the mercury through a telescope, the position of
meniscus was estimated to one-tenth of a division.

ne of these thermometers had a tube of very small bore,
, although it was mounted near the stirrer motors and
rated slightly, it probably suffered from "backlash."(5)
ring a period of five days, the reading of this thermometer
not observed to change by more than ±0·002° C. The
er thermometer had a much larger bulb and a corre-
ndingly large diameter tube; during the same period, its
ding changed by ±0·003° C. In addition to "backlash,"
nercury-in-glass thermometer may suffer from change of
o.(6) Although there was no evidence for this in the
sent work, it seems safer to rely on the results obtained
h the thermistor.

PROPOSED MODIFICATIONS

A description has been given of the apparatus actually used; there are several ways in which it could be improved or simplified. The life of the thermometer depends on the rubber stoppers, one of which has been immersed in the tank for four months and shows signs of perishing. A new, all-metal thermometer will be made to replace it.

The cost could be reduced by replacing R_5 and R_6 with wire-wound fixed resistors, as the photocell bridge can be balanced sufficiently accurately by careful adjustment of the prism. Resistors R_8 and R_9 could be replaced by a single wire-wound potentiometer. By a more suitable choice of R_{12} and R_{13}, or by using an additional rheostat, the Variac could be discarded. Although no failure has as yet occurred, a relay or circuit-breaker will be connected in series with the galvanometer lamp in the box so that, if the lamp fails the control bridge will be disconnected from the accumulators and hence the galvanometers will be protected.

CONCLUSION

The measurements confirm that the temperature of the bath can be kept constant to within ±0·005° C for periods of several hours, thus satisfying the immediate requirement. The control circuit is very simple, and its operation is not significantly affected by small changes of the mains voltage or of the e.m.f.'s of any of the cells used. It is sufficiently sensitive so that operation will occur if the temperature changes by 0·001° C, but during the course of several days it suffers from appreciable zero-drift. Of this, ±0·001° C is associated with the galvanometer–photocell amplifier, and this seems capable of improvement; the remainder is associated with the control bridge itself, and if in the future it is desired to eliminate this it may be necessary to house the whole equipment in a constant-temperature room.

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Laboratory and workshop notes

An electromechanical timer

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[*Note first received* 16 *November*, 1956, *and in final form* 21 *January*, 1957]

Although the timer described in the present note was designed and built for a particular purpose, i.e. that of assisting in potato blight forecasting,* it is felt that the unit has many everyday uses, particularly where long intervals of time must be measured automatically for certain warning purposes.

The timer may be used to provide an indication that some condition (e.g. a critical temperature or pressure of some process) has been held continuously from its onset for a chosen interval of time. In the event of the condition lasting for less than the chosen interval the unit is automatically reset to "zero" ready to resume timing should the condition recur. By permanent completion of the operating circuit, to be described later, the unit may also be used as a simple timer.

In the present device, which uses a machine screw driving a half nut for timing purposes, the interval of operation with automatic warning can be varied between twelve and fifty hours. These limits can easily be expanded by changing the pitch of the screw and half nut and/or altering the screw speed. Details of the timer in the operating position are shown in the figure and the method of working is as follows.

Via suitable contacts (e.g. a temperature or pressure sensitive switch) the specified condition is caused to close the energizing circuit (12 V, d.c.) of an electromagnetic relay of which only the flapper *R* is shown. Flapper *R* actuates the relay contacts to complete the circuit of a synchronous motor (Evershed and Vignoles type MBH 250 V, 50 c/s) which drives the 20 turns/in. machine screw *A* at 1 rev/h. (For clarity the thread is not depicted as 20 turns/in. in the figure.)

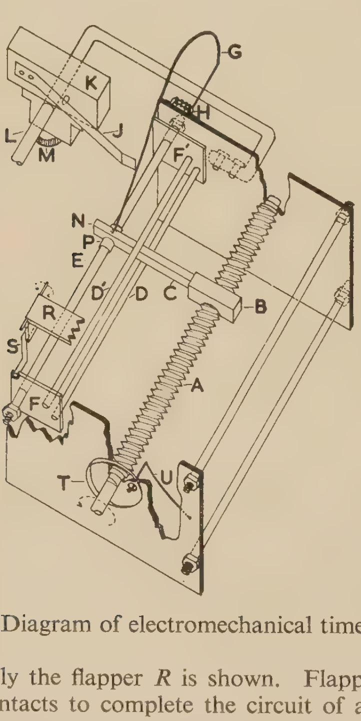

Diagram of electromechanical timer

The flapper also serves, by means of an attached striker *S* to actuate the assembly *FDD'F'*. This rigid structure, composed of the rods *DD'* soldered to the arms *FF'*, hinges on rod *E*. When *S* operates this structure it in turn depresses the arm *C* and so engages the half nut *B* with the thread on *A*. The other end of *C* has a sleeve-bearing *P* which travels along *E* as the half nut progresses, eventually bringing the extension piece *N* to bear on the operating lever *J* of the micro-switch *K*, the position of which can be adjusted and locked on the rod *L* by means of the knurled screw *M*. When *K* is operated electric power is transferred to the warning device from the motor, and the timer stays in this state until it is switched off at the mains supply.

To reset the timer, the spring action of the contact blades on the relay is used as the returning force which lifts the half nut off the thread, and spring *G* restores the half nut arm to its "zero" position. Spring *G* (30 s.w.g. piano wire) has one end fitted into a hole drilled in *C* whilst the other end is wound in a helix which can hinge freely on rod *H* to prevent the spring *G* locking when near full compression.

To allow for variation in the starting position of the thread on *A*, and thus allow the half nut to engage at any setting of the screw, the faced cam *T*, made of Perspex and attached rigidly to the shaft of *A*, varies appropriately the return stop *U* for the half nut. One end of *U* (30 s.w.g. piano wire) is turned back on itself to form a smooth contact with the operating face of the cam. The necessary spring action is obtained by bolting the other end of *U* to one end plate of the timer. Introduction of this stop produces a possible error of half an hour in the timer which is negligible for the forty-eight hour interval associated with potato blight forecasting.

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A controllable source of low-pressure hydrogen

By A. E. Barrington, Ph.D., B.Sc., A.M.I.E.E.,* and F. T. Turner, B.Sc., Grad.I.E.E.,† Services Electronics Research Laboratory, Harlow, Essex

[*Note received* 11 *February*, 1957]

Gas-discharge devices operating at gas pressures of a few millimetres of mercury and relying on a supply of hydrogen from heated replenishers (hydrides of titanium, zirconium thorium) have been in use for some time. Only limited information, however, is available as to the properties of these materials when hydrogen at a pressure of the order of 10^{-2} mm of mercury is required.(1) Experiments in this pressure range are usually performed with a controlled leak and needle-valves are widely used for this purpose. The performance of needle-valves depends on the volume of the system and the speed of the vacuum pumps, and some skill may be required to obtain reproducible results, particularly if the phenomena under investigation depend very critically on the gas pressure. Further difficulties may arise if, in order to obtain a controlled atmosphere, the system has to be outgassed at high temperature. The device described in this note(2) provides an accurate and reliable means of pressure control under such conditions and has given satisfactory performance in sealed-off systems for long periods.(3,4,5) shown in the figure, a nickel-gauze cylinder (100 mesh) unted on an alumina-coated heater. The active material conium powder (300 mesh) suspended in acetone and with a nitrocellulose binder. The suspension is brushed he gauze until an even coating is obtained. The heater unted on a two-wire glass pinch which may be sealed

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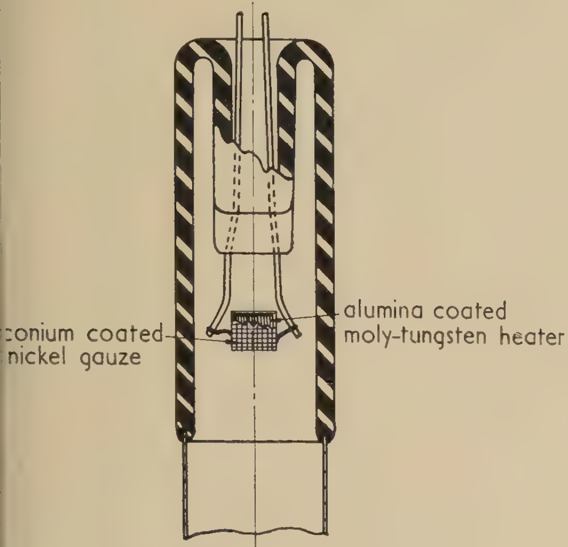

Source mounted on glass-pinch

vacuum vessel in the usual way. For satisfactory tion, it is desirable to bake the system while pumping bout one hour at 450° C; it is then allowed to cool to temperature. The heater is run at about 1000° C for seconds and since the thermal contact between heater auze is poor, little hydrogen is released from the hydride. ugh nominally pure zirconium was used, sufficient ities of hydride were always present and no additional gen activation was required. If, however, this should ne necessary, the system is filled with hydrogen from a der below atmospheric pressure and the temperature of auze is raised slowly to about 400° C. The system is pumped and baked as before.

e following data are typical of a sealed-off system of m³, the source containing 25 mg of zirconium on a area of approximately 1 cm².

Typical data for sealed-off system of 160 *cm*³

er voltage	*Gauze temperature (° C)*		*Hydrogen pressure (mm of mercury)*	
	(*a*)	(*b*)	(*a*)	(*b*)
1·0	320	330	0·002	$<$0·001
1·5	430	450	0·018	0·001
2·0	497	535	0·061	0·005
2·5	546	600	0·100	0·015
3·0	605	658	0·150	0·035
3·5	660	710	$>$0·150	0·057
4·0	710	760	$>$0·150	0·070

lumns (*a*) refer to a source baked at 450° C only, nns (*b*) to the same source when pumped for a further in with the gauze at 500° C. It is seen that the hydrogen ure materially affects the gauze temperature (measured a platinum/platinum-rhodium thermocouple) at constant r voltage. On cooling, the absorption of hydrogen by e (*a*) was slow and after a few temperature cycles became increasingly sluggish; source (*b*), on the other hand, reduced the pressure to 5×10^{-6} mm of mercury in 5 s and after 30 s to less than 10^{-6} mm of mercury. For optimum performance the source is out-gassed at about 500° C until the rate of release of hydrogen at the required operating pressure is approximately equal to the pumping speed of the backing pump.

The maximum operating temperature (760° C) is well below the alloying temperature of zirconium and nickel, and reproducible performance of replenishers processed as above has been obtained for over 1000 temperature-cycles; shelf-lives of over two years have so far been observed. Vibration tests to examine adhesion of the coating have also been satisfactory.

The source may be exposed to air at atmospheric pressure when cold without impairing its properties, provided it is completely reprocessed. The warm-up period is of the order of a minute; more rapid heating, if desired, may be obtained by heating the gauze directly, or by electron bombardment. It has been suggested that a source of this type might also be useful where a low-pressure supply of the rarer isotopes of hydrogen is required; furthermore, the excellent gettering properties of zirconium at the operating temperature would prevent contamination of the filling gas by oxygen, nitrogen or carbon dioxide.

The device was developed at the Services Electronics Research Laboratory, Extension, Harlow, and permission has been obtained from the Admiralty to publish this note.

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The location of events in nuclear emulsions

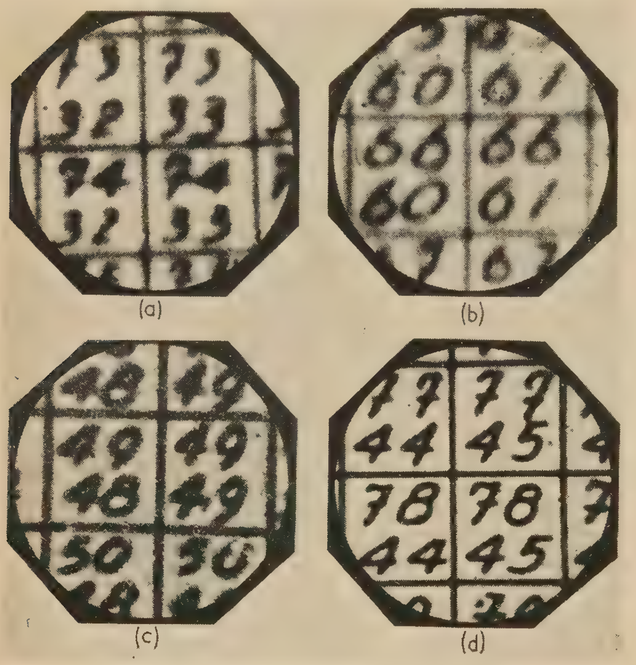
By J. H. Fremlin, M.A., Ph.D., F.Inst.P., and Mrs. J. Mathieson, Department of Physics, University of Birmingham

[*Note received* 17 *December*, 1956]

The great amount of labour which is often needed to find rare events in nuclear emulsions makes it essential to have a reliable method, and very desirable to have a simple method of recording their position when found. A very satisfactory system is that developed by Prof. Huntley⁽¹⁾ of the University College of the Gold Coast, and by Dr. Vanderhaeghe⁽²⁾ of Brussels in which a large numbered co-ordinate system is photographed, and suitable small-scale transparent copies fixed to the nuclear emulsions before examination. It is the purpose of this note to describe two modifications of this method, which have proved cheap and convenient in certain cases.

In the first, a thin second emulsion has been poured on the glass side of each plate after the main event-bearing emulsion has been developed and dried. Over-age liquid emulsion, type G5 (by Ilford Ltd.) is very fine-grained and is entirely suitable. A print from a grid negative can then be made on this subsidiary emulsion, the main emulsion being protected if necessary during processing. A grid so formed cannot possibly be displaced (Fig. *a*). In the second, the grid is printed direct on to the bottom of the main emulsion through the glass support, and allowed to develop during the normal processing of the plate. Light penetration into the emulsion is only about 5 μ if a suitable exposure is made, and a heavy particle track can be followed through the darkened region if necessary, using a high-power objective, although the figures of the grid are clearly legible when using a low power. This method has proved extremely useful for use with cyclotron-exposed plates. Here in many experiments, all tracks enter the upper surface of the emulsion and, if the emulsion is thick enough, all events occur well away from the grid at the bottom. Photography of such events is quite unaffected by the presence of the grid, and no events can be lost even if—as has happened sometimes in one of our rare spells of dry weather—the entire emulsion comes off its glass support.

One or two points of interest arose in the method of printing. Since printing was required on the bottom of the emulsion, through glass about 1½ mm thick, projection printing was the obvious method. The quality obtained with a fair—but not excellent—photographic lens, however, proved to be rather poor (Fig. *b*). The width of lines composing the figures desired was only 30 μ and a flat image was required covering 5 × 10 cm. Contact printing with a "Pointolite" source at 15 ft, to avoid light spread between negative and emulsion, proved even worse; curiously blotched and often fuzzy prints being obtained (Fig. *c*). It occurred to us, however, that this might be due to lack of flatness in the negative, especially the "grooves" left by the removal of silver from the clear areas.(3) We therefore placed a drop of liquid (carbon tetrachloride, but any liquid harmless to the negative and of refractive index near that of gelatine would do) between negative and glass and eliminated the difficulty entirely. Almost equally good results were obtained using as "distant point source" a perfectly ordinary 60 W ceiling lamp with an opaque shade to keep light from the ceiling, the printing frame being placed on the floor 7 ft below it, suitable exposure for C2 plates being 5 s. The emulsio used in preparing the figures were exposed for a longer tim than would normally be desirable, in order to give results reproducible in print (Fig. *d*).



Prints of grids under various conditions

(*a*) Contact print on over-age G5 emulsion poured on back of event-bearing plate. (*b*) Projection print through glass on to back of emulsion. (*c*) Simple contact print through 1½ mm of glass by "Pointolite" at 15 ft. (*d*) As (*c*) but with a drop of carbon tetrachloride between negative and glass.

We are most grateful to Dr. Vanderhaeghe for supplying us with the negatives used.

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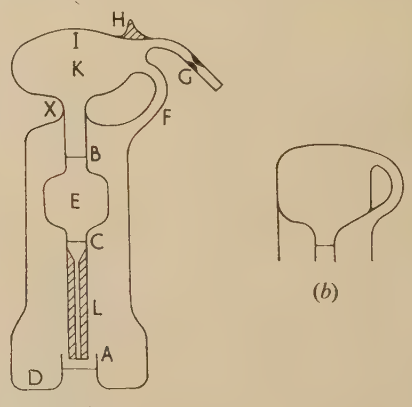
A new capillary viscometer

By N. N. Greenwood, M.Sc., Ph.D., and K. Wade, B.Sc., Department of Chemistry, University o Nottingham

[*Note first received* 12 *December*, *and in final form* 2 *April*, 1957]

The measurement of the viscosity of liquids which unstable in air presents certain difficulties which are readily solved by the use of conventional types of capill viscometer. When measurements are required over a ra of temperatures it is inconvenient to adjust the level of t liquid at each temperature, and in those cases where liquid or its vapour attacks tap grease, it is also inconven to use variation in pressure to raise the liquid before e measurement. Sublimation of the liquid to cooler parts the apparatus is a further source of error in measurement higher temperatures. Several viscometers have been descri which overcome one or more of these difficulties,(1) but may be overcome by using a totally immersed, sealed, all-g viscometer of the type illustrated in the figure (*a*). A sim instrument has been described by Plank and Hunt(2) but t is large and less easy to operate. The present instrume differs from theirs and from the one designed by Bank Davies, and Rudge(3) principally in the method used circulate the liquid.

The viscometer is a capillary-flow instrument with a w *A* surrounding the lower end of the capillary so that t level to which the liquid flows is independent of the volu



(*a*)

(*a*) Viscometer showing (*b*) alternative arrangement for upper bulb uid provided this is not so great as to fill the sump *D*. . V-cuts in the weir facilitate the steady flow of liquid he sump and ensure that the liquid level remains constant; wise there is a tendency for the liquid to build up and overflow discontinuously.

test liquid is poured or distilled into the apparatus ı is sealed off *in vacuo* at *G* after the liquid has been sed. Liquids which are stable in air may, of course, be l off at atmospheric pressure. The liquid flows from pper bulb *K* through the inner compartment *E* and the ary *L*, and is timed as its upper surface passes the d marks *B* and *C*. After a timing run the liquid is ed to the compartment *E via* the side tube *F* and the *K* by clockwise rotation of the instrument through 360° plane of the paper. The viscometer is held in a metal which can be rotated from above by means of a chain ng round a sprocket wheel on one of the axles of the . The knob *H* on the viscometer enables it to be d in an upright position by means of a glass tube lowered position through a guiding sleeve above the instrument. position of this locking tube is adjusted before a run at the instrument is held with the capillary vertical). Alternatively the locking device may be built into etal clamping frame.

e dimensions of the viscometer are not critical. Two ments which have been used satisfactorily have an ll length of 14 cm and require a working volume of ml, the volume of the compartment *E* being about The capillary tube is 35 mm long, and is 0·5 mm and mm diameter in the two models. The instruments, which originally constructed to measure the kinematic viscosity olten addition compounds of gallium trichloride and ed inorganic complexes, were purposely designed to have ort length and small working volume. However, their acteristics are improved if the capillary is made somewhat er (say 10 cm). Other obvious modifications are:

to have the inlet tube *G* in position *I*; this facilitates the ing of the capillary but increases the susceptibility to age errors;

) to eliminate the neck *X* as shown in the figure (*b*); this its a longer capillary for the same overall length and lifies the glass blowing.(4)

e advantages of the present instrument over the more entional viscometers are:

it is robust and simple to operate; recharging of the by rotation of the apparatus is quicker than blowing or ing up the liquid and it eliminates the possibility of amination from the gas used to manipulate the liquid s;

) the viscometer is useful for unstable or highly reactive ds since it is a sealed all-glass apparatus;

i) it is also useful for volatile liquids and for liquids ve their normal boiling points; with normal glass tubing moderate care in construction the apparatus should withd an internal pressure of 4–5 atm without danger;

v) there are no charging errors, i.e. no delicate adjustment e liquid level to a fixed mark, since the effective head is pendent of the volume of the liquid. For a similar reason nstrument can be used over a wide range of temperatures out continual readjustment of volume to compensate for mal expansion of the liquid. Pyrex-glass instruments be used up to about 400° C and fused silica ones at higher peratures, provided that there is no chemical attack by molten compound;

) errors in alignment of the capillary have negligible t on the efflux time since the outlet over the weir is almost directly beneath the inlet to the capillary. For Ostwald-type viscometers a 1° tilt of the capillary from the vertical in the plane of the viscometer causes an error of about 0·4% in the result. Calculation shows that for the present design a similar tilt leads to an error of 0·15%, and if the capillary were increased in length from 3·5 cm to 10 cm the error would be halved again. It has been confirmed experimentally that appreciable errors in alignment have very little effect on the time of outflow.

The main disadvantages of the new design of viscometer seem to be:

(i) difficulty in cleaning the instrument: it is difficult to remove small particles of solid if these become lodged in the capillary, without blowing a hole in the upper bulb at position *I*. In this laboratory mechanical obstruction of the capillary is avoided either by distilling the test liquid into the viscometer, or if this is not possible, by pouring the liquid into the instrument through a 1 cm diameter sintered-glass disk.

(ii) surface tension affects the mean head of liquid by causing a build-up in the weir before drain-off begins and by exerting a traction on the surface in the upper bulb. These effects are most noticeable with liquids of high surface tension but can be reduced both by lengthening the capillary and by calibrating the viscometer with a liquid whose surface tension is approximately the same as that of the unknown. Moreover, surface tension has little influence on the precision with which relative measurements on the one liquid can be made at a series of temperatures. Drainage errors in the present viscometer are no more serious than in the conventional viscometers providing that the inlet tube *G* is on the same side of the instrument as the connecting tube *F*. It has also been found that there is no difficulty in temperature control, even though the viscometer bulb is separated from the outer wall of the apparatus by a vapour space.

The authors gratefully acknowledge the award of a D.S.I.R. maintenance grant to K. W.

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An apparatus for growing single crystals of gallium arsenide

By J. L. Richards, Ph.D., Services Electronics Research Laboratory, Baldock, Herts.*

[*Note received* 20 *December*, 1956]

It is necessary for most applications to produce semiconductors in single crystal form with the crystal lattice distorted as little as possible. For this purpose the well-known method of Czochralski⁽¹⁾ has proved most suitable. In this technique a single crystal is produced by raising a seed crystal vertically out of a melt. The application of this method to the production of single crystals of gallium arsenide and indium arsenide has recently been described by Gremmelmaeir⁽²⁾ in which a magnetic arrangement is used to withdraw the seed from the melt. This author also describes the condition which it is necessary to set up inside the apparatus when growing crystals of compounds which decompose at the melting point. The apparatus must be closed and all surfaces with which the vapour can come into contact must be maintained above the sublimation temperature of the volatile component. Under these high temperature conditions (650–1300° C in the case of gallium arsenide) the arsenic vapour is extremely reactive and care must be taken that only quartz and graphite come into contact with this vapour.

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* Now with Philco Corporation, Philadelphia, Pennsylvania, U.S.A.

The main difficulty in the development of such an apparatus lies in the design of a suitable seal which will be effective at the high temperatures involved, and through which a mechanism can be arranged for withdrawing a seed from the melt. In this laboratory a suitable withdrawal arrangement was developed using a liquid gallium seal. The apparatus is shown in Fig. 1. The graphite crucible containing the melt is located inside the stationary quartz tube, the upper part of which takes the form of a narrow deep well. The well is half filled with liquid gallium. The withdrawal apparatus is lowered into the well to form a seal. Both vertical and rotational motion are achieved by some suitable motor drive applied to the quartz shaft. The crucible is heated inductivel and the upper portion of the apparatus is maintained at 650° by means of the resistance furnace. The seed holder is mad up of four quartz rods fixed parallel to each other in th form of a square. The square section seed is held in positio by the springing action of the rods. A Pyrex cover serves t enable the apparatus to be evacuated and then filled wit dried nitrogen which leaks slowly out of the flanged join In this way a nitrogen blanket at a pressure of one atmospher is maintained over the liquid gallium during the pullin operation. Pressure differences arising in the apparatu during operation are automatically relieved by gas bubblin to and fro across the gallium seal.

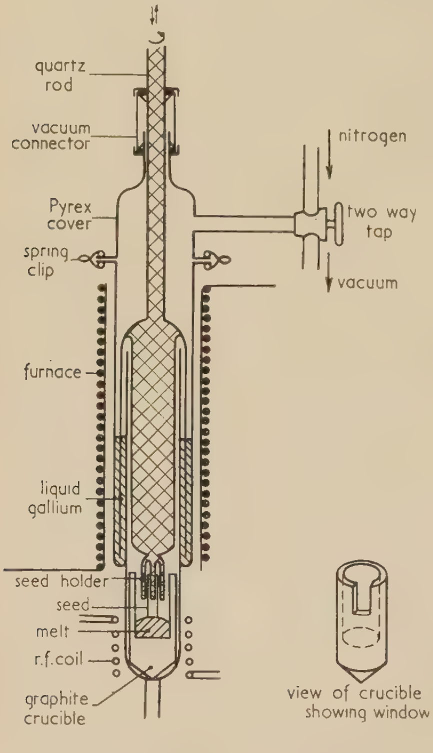

Fig. 1. Crystal growing apparatus

At present single crystals 3 cm in length and 1 cm diameter have been grown from relatively impure materi (see Fig. 2), their length being limited by the amount

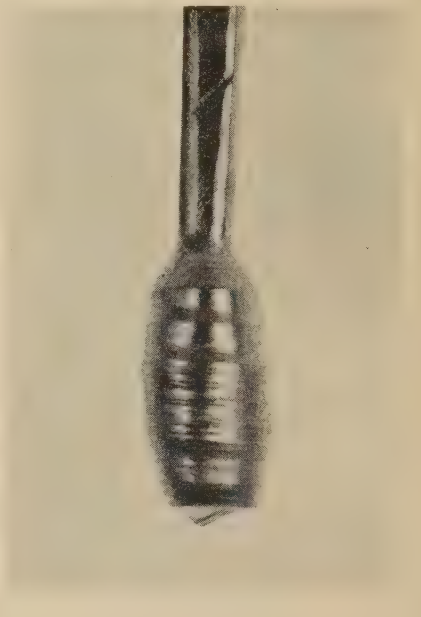

Fig. 2. Gallium arsenide single crystal

gallium available for use in the trap. The crystals showe p-type conductivity and had restivities of a few ohm cn Suitable crystals for seeding were cut out of large ingots gallium arsenide which had been subjected to direction freezing. Since these seeds were oriented in the (1 direction, crystal growth has so far been limited to th direction.

By suitable replacement of the metal in the trap, apparatus can be adapted to grow crystals of other thermal unstable compound semi-conductors. Work is going on present to develop the apparatus further and to grow cryst of indium arsenide.

Acknowledgement is made to the Admiralty for permissi to publish this communication.

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Correspondence

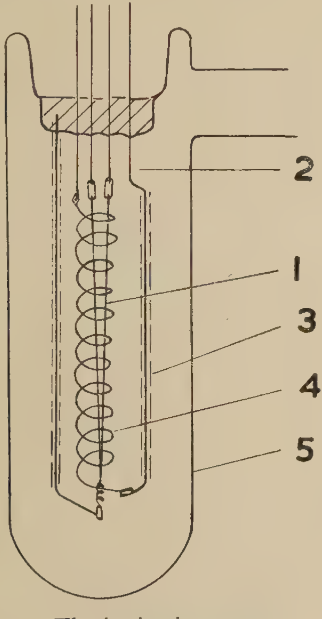
A new type of ionization-pump

the aid of the Bayard–Alpert(1,2,3) gauge-pump it is ble to obtain ultra-high vacua, making it possible to out experiments in gaseous and physical electronics in mely favourable conditions. Nevertheless, if the experi-al vessel contains large metallic surfaces and especially if surfaces are to be outgassed for several thousands of ; after sealing off, the pumping speed of the Bayard–:t gauge-pump (0·03–0·04 l./s at 10 mA electron current) roved insufficient for maintaining a very low pressure.

order to satisfy this requirement, we have developed an ation-pump with higher pumping speed than that of ng types, which furthermore is simpler in construction out-gassing.

: have adopted the hypothesis of Alpert,(2) Schwartz(4,5) others which has been verified directly by J. R. Young,(6) ding to which the ions are adsorbed also on the glass of the Bayard–Alpert gauge-pump. (It is interesting to that Young, when using a Bayard–Alpert gauge, in a carefully planned set-up, has obtained pumping speeds 0·1 l./s.) Moreover, we suppose that the contribution e central wire of the gauge to the pumping speed is gible. This hypothesis is supported by the observation the pumping-speed of a Bayard–Alpert gauge-pump, ing at a pressure of 10^{-8}–10^{-9} mm of mercury does not ish sensibly for months. Owing to its small dimensions, ption on the central wire could in no case explain this imental fact.

: proposed pump shown in the figure has only two odes: a tungsten filament of 0·1 mm diameter and a lrical grid of about 10 mm diameter, made of tungsten wire of 0·2 mm diameter. The glass wall, 50 mm in diameter, plays the role of the third electrode. This is due to the fact that, if the filament is heated before applying a voltage between grid and filament, the electrons which hit the glass wall with an energy of several electron-volts, will charge it negatively to a potential close to that of the filament (the secondary emission coefficient is <1 at such small energies).



The ionization pump

tungsten filament, diameter 0·1 mm; (2), molybdenum -in-wire, diameter 1 mm; (3), glass cover for preventing ing of molybdenum wires; (4), tungsten grid, diameter 0·2 mm; (5), glass wall.

If subsequently one applies 200 V (or better, 300 V) between grid and filament, the exact working conditions of the Buckley–Dushman gauge are reproduced, having the glass wall as collector. This "collector" has a diameter of 50 mm and a negative voltage of only a few volts with respect to the filament. Therefore the number of ions created outside the grid at an electron current of 10 mA is 3–4 times as large as that obtained in a Buckley–Dushman high-sensitivity gauge. Thus we may expect an ion current of 1–$2 \cdot 10^{-n}$ A at a pressure of 10^{-n} mm of mercury and an electron current of 10 mA.

If we admit that all the ions captured by the "collector" are adsorbed (almost all ions reach the wall with energies in the range of 100 to 300 eV) we get a pumping speed of 0·2–0·4 l./s. There is no danger of the glass wall becoming positive due to ion capture, as any increase of its potential leads to a large increase in the number of electrons hitting the wall, and so neutralizing the effect of the ions. (Even at a pressure of 10^{-4} mm of mercury the number of electrons is still 100 times the number of ions.)

The proposed pump is easier to build and outgas than the Bayard–Alpert gauge, since it does not contain the most delicate part of the latter, i.e. the central wire.

In order to obtain optimal performances of the pump, very accurate outgassing is necessary. This is achieved at the same time as the outgassing of the experimental vessel (generally the pump has been studied only in connexion with the experimental vessel, and not by itself). The outgassing of the vacuum system lasted for about 80 h.

The outgassing of filament and grid, together with the other metal pieces, takes about 60 h, with 3–4 interruptions, during which the vessel and pumps are outgassed in a furnace at 460–470° C, i.e. for about 20 h. The filament is heated to a temperature higher than the working temperature, corresponding to an emission current of 10 mA; this is achieved by passing a current of 1·5–1·6 A. The grid is heated to 1100–1200° C, also by conduction currents and if very accurate outgassing is required it is subjected to electron bombardment (600–1000 eV). This is not necessary for the outgassing of the grid proper, but of those parts of the support wires which are not covered by glass. The latter operation must last for more than one or two hours and must be carried out before the final outgassing in the furnace. After this the grid may be subjected to electron bombardment but only for 10–15 min and in high vacuum ($\sim 10^{-7}$ mm of mercury). This is necessary because while outgassing with the grid voltage on, gas is deposited in the walls of the pump.

We want to stress the need for a careful outgassing of the grid. During the normal working of the pump, the grid and the free parts of its support wires are subjected to electron bombardment by 200–300 eV electrons. Therefore, these parts are heated, a release of gases becomes possible and the pump may become useless.

The proposed pump is not suitable for measuring pressures. For this reason, a Bayard–Alpert gauge must be used both during the outgassing and for measuring the pumping speed.

In order to determine the pumping speed we use an equation of the type proposed by Alpert(2)

$$\frac{dp}{dt} = -\frac{S_A}{V}p - \frac{S_p}{V}p + \frac{G}{V} \tag{1}$$

It describes the time rate-of-change of pressure in a system containing a Bayard–Alpert gauge of pumping speed S_A l./s, a pump of the type proposed by us, with pumping speed S_p l./s and a gas-source, e.g. the heated metallic parts of the system, the walls of the vessels, etc., with a gas yield G, expressed in mm of mercury × l./s; p is the pressure at time t and V the volume of the system. It is supposed that during the measurements G does not change with pressure within very large limits. Young(6) has proposed two corrections to this formula. One is due to the fact that "the number of available ion pumping sites decreases with gas pumped." If the pump has worked for a sufficiently short time and at a sufficiently low pressure before the pumping speed is measured, so that only 1–5% of the ion pumping sites are occupied, this correction may be neglected. The second correction refers to the fact that some of the pumped gas is evolved. The number of such evolved molecules is, of course, proportional to the quantity of gas pumped during the history of the pump. No doubt the increase of this quantity during measurement leads to a completely negligible increase of the amount of evolved gas. We may therefore consider this gas-source as constant, and add it to G.

Integrating (1) under the stated conditions, we obtain

$$S_p = \frac{V}{\Delta t}\ln\frac{(S_A + S_p)p_i - G}{(S_A + S_p)p_f - G} - S_A \tag{2}$$

where $\Delta t = t_f - t_i$ is the time the pump has worked, and $p_i = p(t_i)$ and $p_f = p(t_f)$.

Equation (1) allows us to define an equilibrium pressure p_0 by putting $\left(\frac{dp}{dt}\right)_{p = p_0} = 0$ given by

$$p_0 = \frac{G}{S_A + S_p} \tag{3}$$

Thus (2) becomes

$$S_p = \frac{V}{\Delta t}\ln\frac{p_i - p_0}{p_f - p_0} - S_A \tag{2'}$$

We have determined S_A by putting $S_p = 0$, i.e. stopping the pumping action of the pump. Thus (3) becomes

$$p_0' = \frac{G}{S_A} \tag{3'}$$

and (2′) becomes

$$S_A = \frac{V}{\Delta t}\ln\frac{p_i - p_0'}{p_f - p_0'} \tag{2''}$$

S_A has been determined in several measurements and then repeated measurements have been made to determine S_p. The pumping speed at an electron current of 10 mA and a grid voltage of 200 V is $S_p = 0{\cdot}18$–$0{\cdot}2$ l./s and for a grid voltage of 300 V $S_p = 0{\cdot}25$–$0{\cdot}27$ l./s. Measurements have been carried out at pressures between 10^{-5}–10^{-8} mm of mercury and have shown that S_p is practically independent of pressure.

Using such a pump together with a Bayard–Alpert gauge we have been able to outgas for several months a nickel cylinder (of 7 cm^2 area) at a temperature of 1000° C and constant pressure of $1{\cdot}10^{-9}$ mm of mercury. If necessary two or more such pumps may be used simultaneously.

A detailed account of the above work, especially of the problem of the wall potential and the measurement of pumping speed will be published in *Studii si cercetari de fizica*, (1957).

Institute for Atomic Physics,
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Bucharest.
George Comsa
Geavit Musa
(31 December, 1956

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Measurement of low deuterium concentration in water by means of float method

A few years ago Sapirstein* proposed an original de metric method, based on a float device, for the measurem of the deuterium concentration in water samples. Howe in Sapirstein's opinion, a previous calibration with kno samples was necessary in order to know the absolute va of measured concentrations, but Cerrai, Marchetti Silvestri† showed that Sapirstein's method could also be u as an absolute one.

According to Sapirstein, the method consists essentially determining the temperature at which the density o previously purified sample of water is equal to the effec density of a float. The present note deals with an impro ment to this method as described by Cerrai, Marchetti Silvestri.

Accuracy currently achieved by them was about 3 × 10 $D/(D + H)$ in samples having a deuterium content up 10%. The temperature t °C at which the float starts risi from the bottom of the test tube containing the unkno sample is determined. The value t_0 °C is successively det mined using a sample of distilled natural water. The quanti $\Delta t = t - t_0$, is a known function of the deuterium conc tration N in the sample for any given float.

Since the difference in specific gravity between deuteri oxide and protium oxide is fairly constant from 6 to 40 one can improve accuracy to a large extent if the temperat t_0 is so chosen that the derivative dt/dN is large.

The difference in temperature Δt for the same difference deuterium concentration is greater as the temperature t_0 lowered down to the temperature of maximum density water. This is especially true when the deuterium conc tration in the water sample is low (approximately 0·5 because the value $\Delta t/\Delta N$ decreases when N increases. F it is not advisable to choose too low a value of t_0 (for instan less than 8° C), because starting of the float cannot be ea determined.

The rate of the temperature descent of the water bath m be sufficiently low in order that the temperature of ometric bulb and of the test tube be equal, within the acy of the thermometer readings.

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* Sapirstein, L. A. *J. Lab. Clin. Med.*, **35**, p. 793 (1950).

† Cerrai, E., Marchetti, C., and Silvestri, M. *Nu Cimento*, **9**, p. 530 (1952).

test the apparatus, some experimental measures have carried out on three samples in the concentration range 0·03 to 0·1% deuterium.

following table contains some experimental data. The etical value of the concentration (N% theor.) of the e obtained by dilution, was calculated by weighing and tope balance.

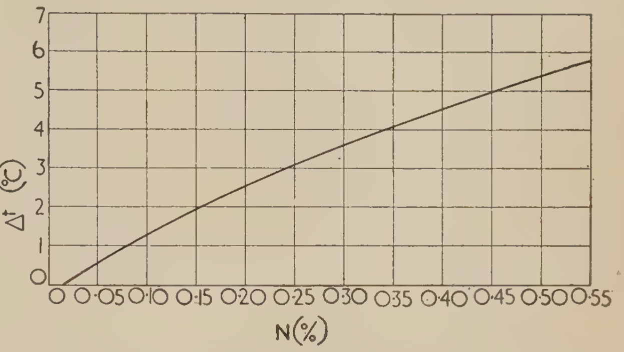
Experimental data from three samples

Sample	*N% measured*	*N% theor.*
1	0·0993 ± 0·0002	0·0991 ± 0·0003
2	0·0576 ± 0·0004	0·0573 ± 0·0002
3	0·0339 ± 0·0001	0·0340 ± 0·0001

standard determination consists in the preparation of ample of distilled natural water, one of the unknown e and one of a new sample of distilled natural water. r readings are made for each sample, total expenditure ne for one determination is about two hours. The atus did not show any appreciable memory effect.

accuracy of the analysis carried out by the present od and under these conditions is thus from 2 to 3 parts illion deuterium in hydrogen. On the ground of these , the isotope content of samples in the concentrations of natural water can be determined with an accuracy of the true value of the concentration. This considerable accuracy is obtained at a fairly low price, because no expensive instruments are required.

A tabulation of the relationship between the concentration N and the difference of temperature Δt as determined above is shown in the figure, for t_0 equal to 8° C. It can be seen, in this case, that, for the very low concentration range, $dt/dN = 17°$ C per 1% $D/(D + H)$.



Relationship between the concentration N and the difference of temperature Δt for $t_0 = 8°$ C

Laboratori C.I.S.E.,
Milan,
Italy.

B. Brigoli
E. Cerrai
M. Silvestri

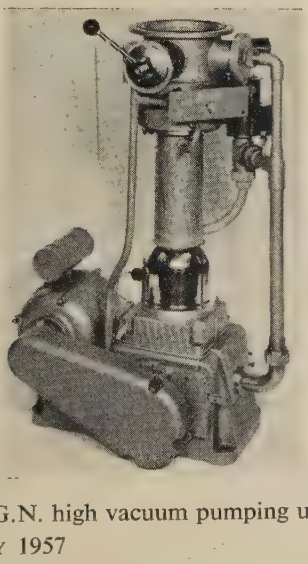
(7 January, 1957)

New instruments, materials and tools

ditor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved cts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

vacuum pumping unit. N.G.N. Electrical Ltd., Cawdor treet, Patricroft, Manchester.

N.G.N. combined high vacuum pumping unit is a ete vacuum unit for connecting direct to any appro- vacuum chamber. The mechanical rotary piston pump which exhausts the gases to atmosphere may be supplied in three sizes or capacities, depending on the individual requirements and the vacuum conditions desired. The rotary pump is used to reduce the backing pressure on an oil diffusion pump which in turn is connected to a water cooled baffle valve terminating in a vacuum flange.



N.G.N. high vacuum pumping unit

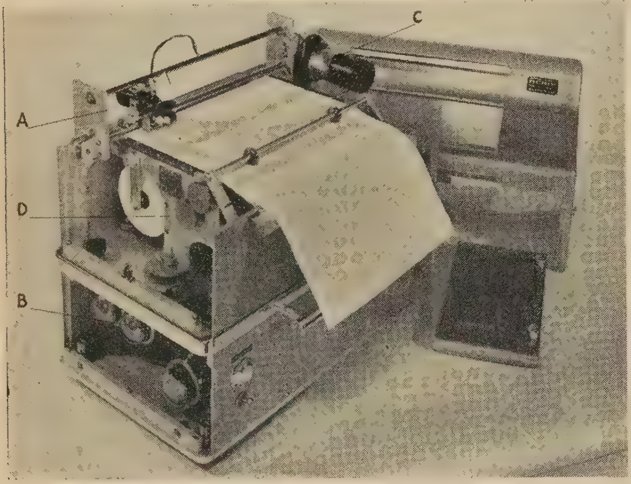
Any of the required vacuum conditions, "rough pumping," "fine pumping," "isolation" or "air admittance" of the chamber controlled may be selected by the operation of a single lever to the desired position on the dial. Each position is interlocked and the unit is protected against power and water supply failure. The three sizes of units have pumping speeds of 25–400 l./sec at 0·1 microns of mercury. The makers claim an ultimate pressure of 0·005 microns of mercury. Each unit is able to pump a proportion of condensable vapours by using the gas ballast arrangement which is supplied as a standard attachment.

Ultra-high vacuum valve. Consolidated Electrodynamics Corporation, 300 North Sierra Madre Villa, Pasadena, California, U.S.A.

The Alpert type VAU-25 laboratory ultra-high vacuum valve is intended for handling pressures of the order of 10^{-10} mm Hg. In such vacuum systems, non-contamination and the ability to be baked out are of highest importance. The valve consists of the valve assembly, which becomes part of the vacuum system, and the driver mechanism which opens and closes the valve. Because they are separate, the valve can be baked out at high temperatures (up to 450° C) without also baking the driver threads and lubricant. The valve assembly consists of a Monel cup sealed off by a flexible Monel diaphragm which can move 0·1 in. Opening into the Monel cup are two $\frac{1}{4}$ in. copper vacuum leads. Opposite the vacuum leads and attached to the inside of the diaphragm is a Monel nose piece with a highly polished 45° conical surface. The driver mechanism contains a differential screw and is rotated by a torque wrench. The screw exerts a force between 1 and 2 tons on the Monel nose of the assembly, forcing it against one of the $\frac{1}{4}$ in. orifices in the cup and closing off the vacuum lead.

General-purpose recorder. Sefram, 74 Rue de la Fédération, Paris XVe, France.

This recorder is intended to be used in conjunction with a mirror galvanometer or other device in which the information is presented in the form of a moving light spot. It consists essentially of a servomechanism which moves a photocell so as to follow a light spot. A pen mechanically linked to the photocell makes a trace on a moving strip of paper. The illustration shows the internal mechanism of the instrument. A spot of light falls on a narrow window in the case of the instrument and strikes the photocell *A*. The output of the cell is fed through the amplifier *B* to operate the servomotor *C* to correct for any position error between the light spot and the cell. The servo-system is stated to be capable of accelerations up to 4 m/s^2 and to have a maximum writing speed of 50 cm/s. The photocell is of the differential photoconductive type and is used in a circuit* which makes its sensitivity independent of the intensity of the light spot. The recording pen attached to the photocell makes a trace 0·2 mm wide on a paper chart having a usable width of 21 cm. The paper can be driven by a synchronous motor at a speed of 12, 30, 60, 120 or 300 mm/h or mm/min. The drums ca take from 100 to 150 m lengths of paper.



Internal construction of general-purpose recorder

A, carriage with photocell and pen; *B*, amplifier; *C*, servomotor; *D*, paper drive.

Scintillators. Nash and Thompson Ltd., Oakcroft Road, Chessington, Surrey.

A new plastic has been introduced for the counting of high energy nuclear particles by the scintillation-photomultiplier method. This material, which is marketed under the name Naton 11, is available in cylinders of diameters 1 to 10 in. It is claimed to have an efficiency at least 60% of that of the best anthracene crystals, and to have a decay time of the order of 3×10^{-9} s.

For apparatus using a liquid scintillator, the powdere material is now available in sealed polythene bags. This ca be dissolved as required in a suitable solvent by the user.

Lovibond Schofield tintometer. Tintometer Ltd., The Colo Laboratory, Salisbury, Wilts.

This redesigned model is said to retain all the merits of original system, but to be much simpler mechanically, not t get out of adjustment, to use one lamp only to illumin both fields of view, and to work at a higher level of illumi tion, which facilitates the matching of dark samples. same instrument is used both for surface colours or tra mitted light, and cells are available up to 6 in. optical de for liquids.

The tintometer employed is the standard model in bl moulded plastic, containing 81 Lovibond permanent gl colour slides, covering the range 0·1–18·0 Lovibond units i each of the three primary colours red, yellow and blue. Th viewing tube is precision-made in brass, with the mirro enclosed by a thin glass cover, and the C.I.E. Davis–Gibs light filter built in. This filter is a double compartme borosilicate glass cell with two 1 cm compartments in whi are placed the appropriate chemical solutions.

The illuminating cabinet and photometric unit consists a metal case of modern design in which is incorporated integrating sphere containing a 250 W projector lam Light is emitted from two apertures, in front of which is circular sleeve, in which are cut two accurately adjuste V slots. This sleeve is rotated by the operator to adjust th relative amount of light allowed to fall on the matchin fields, and a match is obtained by adjusting the glasses f hue and saturation and the photometric device for luminanc Two nomograms are provided; by means of one the colo quality represented by the Lovibond glasses used is in mediately located in its correct position in the colour diagra and *x*, *y*, *z* co-ordinates read off, and the other provides t brightness or luminance factor for the sample, either optical density or brightness as a percentage of the standa white.

The mechanical design is such that it is claimed that the is no back-lash, the instrument cannot get out of adjustme and the whole operation of matching is so easy to understa and handle that no specialized knowledge is needed befo results can be obtained. A ventilating fan and foot swit are provided.

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* Thulin, A. *J. Sci. Instrum.*, **32**, p. 387 (1955).

New books

oratory and workshop notes 1953–1955. Compiled and edited by Ruth Lang. (London: Edward Arnold (Publishers) Ltd.) Pp. xii + 246. Price 30*s*. net.

warm reception given to the first three volumes of these es, originally published in the *Journal of Scientific uments*, prompted the Board of the Institute of Physics ivite Dr. Ruth Lang to prepare this fourth volume which, is preface, Sir John Cockcroft cordially recommends to ratory workers. This series of volumes has become wn in some quarters as "a catalogue of ingenuity," and can equally be said of the new collection. It is divided the following sections: Graphs, records and charts; hanical design and devices; Laboratory and workshop iods and tools; Optical and thermal devices and tech- es and infra-red spectroscopy; Devices for liquids and s; Vacuum and high pressure devices and techniques; trical devices and techniques.

rther handbook of industrial radiology. Edited by W. J. Wiltshire. (London: Edward Arnold (Publishers) Ltd.) Pp. viii + 338. Price 30*s*.

Handbook of industrial radiology—now in its second on—was based on a series of lectures given by the -Destructive Testing Group of the Institute of Physics. se lectures were mainly confined to essentials and the dbook was, and still is, of the greatest value to all con- ed with the application of radiology to industrial purposes. oday, the basic principles of radiological inspection ain unchanged; the methods and techniques discussed in handbook are still essential. At the same time, the eless flow of scientific progress has brought much that is . The development of accelerators has made possible the luction of radiation of high energy and in great intensity; advent of a supply of radio isotopes, with their convenience adaptability, has facilitated many applications of radio- cal methods; electronic progress has made automatic ection more practicable in suitable cases. These and r such advantages have greatly extended the radiologist's ntial field of activity.

was clear that some collected account of these new elopments should be made available to workers in radio- cal inspection, and to provide such an account is the main pose of the present volume. The ground covered in the dbook is not repeated, but some of the subjects crowded of that book (fluoroscopy, stereoscopy and so on) have n included and somewhat fuller treatment has been given some matters, such as the various radiation scattering cesses and the factors affecting radiographic qualities. present book may be regarded as the complement of the dbook and is in no sense intended to supersede it. As ore, each chapter has been written by a specialist in the subject dealt with. The titles of the chapters are: High voltage X-ray generators; Natural and artificial sources for gamma-radiography; Scattered radiation; Radiographic quality and sensitivity; Films and their processing; The reproduction of radiographs; Fluoroscopy; Electrical methods for detection and measurement; Weld radiography; Castings and their radiography; Microradiography; Flash radiography; Stereo methods; Industrial Xeroradiography; An introduction to applied X-ray diffraction methods.

Editorial note:

Once again through the generosity of the editors and the authors the royalties from the sales of the preceding two books will be passed to the Institute of Physics' Benevolent Fund. Not only for this reason but for their own advantage we cordially invite readers to order their copies forthwith and to recommend them to their friends.

Physics of non-destructive testing. Supplement No. 6 to the *British Journal of Applied Physics*. (London: The Institute of Physics, 1957.) Pp. iii + 72. Price 25*s*.

Supplement No. 6 to the *British Journal of Applied Physics* contains a selection of papers presented during the past few months at meetings of the Non-destructive Testing Group of The Institute of Physics. They include most of those read at a conference held in Bristol in July 1956 and it is intended, through this Supplement, to enable engineers, metallurgists and indeed all those concerned with non-destructive testing, to appreciate the importance of the new methods which are resulting from applications of physics to this field and to give them an opportunity of considering how far further suggestions for utilizing the physical behaviour of substances under various conditions can be used and developed as methods for non-destructive testing.

The following titles give some idea of the range of subjects that are covered in the field of non-destructive testing: Some aspects of the mechanical testing of non-metallic solids; Symposium on optical and surface methods of non-destructive testing; The potentialities of X-ray diffraction studies in non-destructive testing; Symposium on principles of penetrant methods; Magnetic properties and the structure of metals; Principles and applications of nuclear magnetic resonance; Optical fluorescence in non-destructive testing; The effects of penetrating radiations on materials; Physical methods in medical diagnosis; The detection of fatigue in metals; Structural changes and energy dissipation during fatigue in copper; Measurement of elastic constants by the ultrasonic pulse method; The testing of fibres and their molecular structure.

The Supplement contains both a name and a subject index and nearly one hundred illustrations.

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

Fellows: A. W. Agar, G. W. Bloomfield, A. C. Copisarow, J. M. Cowley, R. G. W. Croney, J. C. Duckworth, R. D. B. Fraser, A. K. Head, L. E. Lawley, A. W. Pybus, R. M. Sillitto, R. Street, G. A. P. Wyllie.

Associates: J. Allen, D. E. T. Ashby, N. Brearley, L. J. Copley, I. R. Cowan, D. G. Davis, D. N. Davies, W. H. Davies, T. W. G. Dawson, G. A. Doran, A. V. S. de Reuck, D. I. Gaffee, L. F. Hawkes, D. E. Henshaw, V. M. Hickson, R. Hinkley, A. E. Jenkinson, N. Joel, N. K. Jones, A. Keller, L. Krause, J. Law, P. L. M. le Roux, B. Love, W. Mason, L. A. Massam, A. Moore, E. L. Murray, R. E. Newnham, A. F. Nicholson, P. N. Nikiforuk, F. B. Powell, D. D. Randall, E. B. Rodmell, R. L. Rutter, J. V. Sanders, J. Shaw, T. Shingler, E. E. Smith, A. K. Som, G. N. Thomas, L. Thomas, R. H. Whittle, L. H. Wells, A. Williamson, B. Zacharov.

Thirty-nine Graduates, forty-one Students and four Subscribers were also elected.

Automatic measurement of quality in process plants

The Council of the Society of Instrument Technology Ltd., has approved a proposal to hold a Conference this year on the above subject. The Conference will be held at the University College of Swansea from the evening of Monday, 23rd, to mid-day on Thursday, 26th September, 1957.

The main object of the gathering is to provide an opportunity for the users and makers of automatic measuring equipment, and those concerned with research and developments in this field, to meet and discuss their work. It is hoped that the range of topics to be covered will include: *Chemical quality*: Chromatography; Mass-spectography; pH-measurement; Spectroscopy; Titration. *Physical quality*: Density; Moisture content; Refractive index; Viscosity and "consistency." Offers of further contributions on these and other similar topics will be welcomed by the Council.

All communications should be addressed in the first instance to: The Secretary, The Society of Instrument Technology Ltd., 20 Queen Anne Street, London, W.1.

Report of the International Commission on radiological units and measurements

The 1956 recommendations of the International Commission on radiological units and measurements have been published as the National Bureau of Standards Handbook 62. This report, which is divided into four chapters and contains 48 pages, covers the recommendations of the Commission as agreed upon at its meetings in Geneva in April 1956, and replaces its earlier report issued in 1953. The new repor includes an extensive amount of basic information and data necessary to make radiation dose measurements in energy units (rads), and to convert data expressed in roentgens to the equivalent in energy units.

Chapter 1 contains a comprehensive discussion of radiological quantities, units, and symbols. In Chapter 2 guidance is provided for the clinical application of absorbed dose measurements. Chapter 3 presents a detailed treatment o the physical aspects of absorbed dose determination. Reports of the subcommittees are given in the final chapter. Chapter 4 also includes lists of the primary standards, X-ray standards and radioactivity standards available in various countries and laboratories, as well as an extensive bibliography covering much of the subject matter contained in the report.

Copies of this publication may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., price 40 cents.

Radiofrequency Spectroscopy Symposium

The Committee which was appointed at the symposium held under the auspices of the Liverpool and North Wales Branch of The Institute of Physics in Bangor last September announces that it is arranging for the next symposium to be held in the University of Southampton from 19–21 September. The meeting will be mainly concerned with investigations by electron resonance techniques. Further details are available from Dr. D. J. E. Ingram, The University, Southampton, or the Deputy Secretary, The Institute of Physics, 47 Belgrave Square, London, S.W.1.

British Journal of Applied Physics

Contents of the July issue

CONFERENCE REPORT

Summarized proceedings of a conference on electron microscopy—Reading July 1956. By C. E. Challice.

ORIGINAL CONTRIBUTIONS

Some considerations of the magnetostrictive composite oscillator method for the measurement of elastic moduli. By N. B. Terry.

The frequency dependence of noise temperature ratio in microwave mixer crystals By M. E. Sprinks, G. T. G. Robinson and B. G. Bosch.

The impedance of the oxide-coated cathode at ultra-high frequencies. By L. J Herbst.

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The electrical conductivity and permittivity of mixtures. From D. A. de Vries and C. A. R. Pearce.

The depth of surface damage produced by lapping germanium monocrystals From D. Baker and H. Yemm.

New books

Notes and comments

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Ultra-high vacua*

By J. YARWOOD, M.Sc., F.Inst.P., The Polytechnic, Regent Street, London

The use of the ionization gauge both as a pump and as a measuring instrument in the pressure range from 10^{-6} to 10^{-11} mm of mercury is discussed. Experimental results indicate that Alpert's claims regarding electrical pumping speed are justified provided that the initial pressure is sufficiently low. Suggestions are made regarding the disparities between Alpert's results and those of other workers. The omegatron is described and a short survey given of those factors which set the limit to the lowest pressures attainable in a glass envelope.

or the purposes of this article, an ultra-high vacuum is fined as a region in which the total gas pressure is below $^{-6}$ mm of mercury, firstly, because it is at this pressure at the limitations of diffusion pumps begin to become parent and, secondly, because the pressure region between $^{-6}$ and 10^{-7} mm of mercury is interesting in connexion ith the action of ion pumps. Our experiments have been nfined to the use of an ionization gauge as a pump; no count is given here, therefore, of the use of conventional tters to produce ultra-high vacua.

Hickman,(1) Jaeckel,(2) Latham and others,(3) Haefer and inkler(4) and Florescu(5) have all given discussions of the ctors which influence the ultimate low pressures obtainable y oil diffusion pumps. The conclusion from this work is at the chief factor which limits the ultimate is the presence f gases produced by decomposition of the oil in the boiler nd then liberated at the pump jets. This decomposition is celerated by the autocatalytic action on the oil of the etal of the pump,(2) a factor which will be absent in pumps nstructed from glass. Much less data has been published cently on the ultimate vacuum attainable by a mercury iffusion pump used with a liquid air trap—in which decomosition of the working fluid will not occur—though Latham nd others(6) refer to "the peculiar sensitivity of mercury umps to traces of oil or grease contamination."

To obtain eventually very low pressures (order of 10^{-10} mm f mercury) the commonest practice has been to use first a iffusion pump to attain a pressure less than 10^{-6} mm of ercury, isolate the vessel concerned from this pump, and hen continue to remove gas by means of a thoroughly outassed ionization gauge operated within this vessel. Our wn experiments support the contention(7) that, as would be xpected, it is the best practice to begin to use the ionization auge as a pump at as low an initial pressure as possible. To chieve this in small-scale apparatus, a fractionating oil iffusion pump made of glass and with Octoil S, Apiezon C r DC 703 silicone oil as the working fluid is used. Alteratively, as was the case in our experiments, a glass mercury iffusion pump with liquid air trap can be employed.

As pointed out by Alpert,(7) the subsequent pumping action f the ionization gauge must take place in a vessel which is solated by a greaseless valve from the diffusion pump, or he vessel with the ionization gauge within it must first be ealed-off from the pumps. Otherwise, the diffusion pump ill act as a source of contamination at pressures below bout 10^{-7} mm of mercury rather than as a pump.

The recording of low gas pressures is not readily done with accuracy. The McLeod gauge cannot be used below 10^{-6} mm of mercury and is not really satisfactory below 10^{-5} mm of mercury unless an inconveniently large gauge bulb is used. The Knudsen manometer is often stated to be able to record pressures of 10^{-7} mm of mercury and even 10^{-8} mm of mercury. Trials over a long period in our laboratory have shown that a commercial glass Knudsen manometer is not able to register satisfactorily pressures below 10^{-6} mm of mercury, even though the gauge is thoroughly out-gassed by baking at 400° C. The choice is therefore restricted to the use of an ionization gauge of either the hot- or the cold-cathode type. The better constancy and reproducibility of readings with the hot-cathode or thermal ionization gauge together with the fact that it can be used to record pressures down to 10^{-11} mm of mercury, have resulted in the choice of this gauge for almost all the work which has been done. Interesting possibilities remain, however, of extending the range of the cold-cathode, i.e. Penning, gauge to 10^{-8} mm of mercury, or even less.

THE MEASUREMENT OF GAS PRESSURES IN THE RANGE FROM 10^{-11} TO 10^{-6} MM OF MERCURY

Nottingham(8) showed that the lower limit to the pressure range of the conventional triode form of the thermal ionization gauge was chiefly set by the production of X-rays at the positive electrode. Consider the basic operating circuit for this gauge in which the electron collector (called here the grid, for convenience) is at a positive potential V_g (Fig. 1). The incidence of electrons with an energy of V_g eV at this grid will produce there X-rays with a minimum wavelength of λ_{min} given by the Duane–Hunt equation:

$$hc/\lambda_{min} = V_g e$$

where h is Planck's constant, c is the velocity of light in free space, and e is the electronic charge. It is readily shown that for $V_g = 150$ V—a usual value—λ_{min} will be 100 Å approximately. These soft X-rays will release electrons from the ion collector C, which is at a negative potential V_c. The collector current i_c will therefore be due not only to the arrival of positive ions, but also to the release of photo-electrons. The recording of i_c cannot distinguish between these two contributions to the current, one of the components of which, i_+, is the pressure-dependent, positive ion current, and the other, $i_\times$, is a constant irrespective of the gas pressure, but depends on V_g, the electron current to the grid, i_-, and the geometry and materials of the electrodes.

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* Based on a lecture given to the London and Home Counties ranch of The Institute of Physics on 16 January, 1957.

This residual current due to X-rays sets a limit at about 10^{-8} mm of mercury to the lowest pressure recordable by the conventional gauge with a central thermionic filament, coaxial grid and outer cylindrical ion collector electrode. This limit can be reduced, however, to about 10^{-10} mm of mercury or even 10^{-11} mm of mercury if the interception of the X-rays by the ion collector is reduced by some 100 to 1 000 times. This was first achieved in the Bayard–Alpert(9) design of ionization gauge (Fig. 2), whilst still maintaining a sensitivity comparable with that of a conventional design. The usual gauge construction is inverted: instead of using a central thermionic filament with an outer ion collector, two filaments *FF′* are placed outside the grid *G* and the ion collector *C* is a very thin wire along the axis. Two filaments are convenient so that, if required, the flash-filament technique of estimating low gas pressures due to Apker(10) can be used. Fig. 3 shows a readily constructed design made in our laboratory.

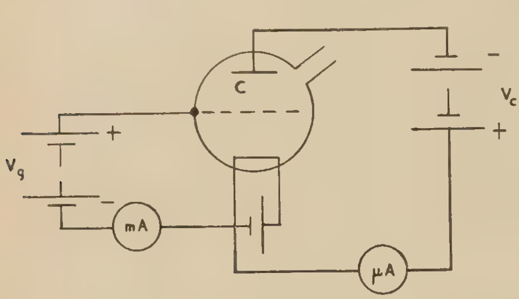


Fig. 1. Basic circuit diagram for a conventional ionization gauge

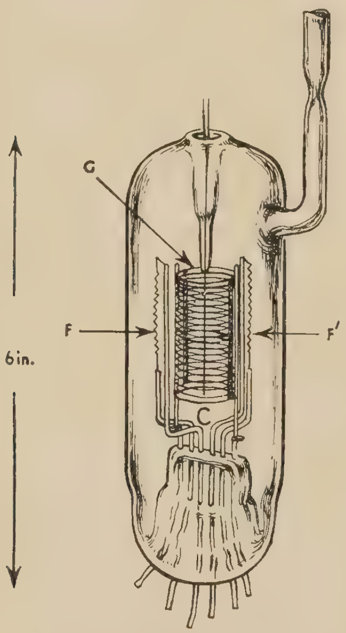


Fig. 2. The Bayard–Alpert design of thermal ionization gauge

Following Alpert,(7) the X-ray limitation to the low pressure performance of a conventional ionization gauge (British American Research, BAR 507, now manufactured by Vacuum Industrial Applications Ltd.) was demonstrated by recording the ion collector current i_c at various grid voltages V_g whilst maintaining constant the collector potential V_c and the electron current i_- (Fig. 4). Three different fixed pressures were maintained and recorded by a Bayard–Alpert gauge connected to the same manifold. At a pressure of 6×10^{-6} mm of mercury, the curve has a characteristic form explained by comparison with the results of Compton and Van Voorhis(11) on the dependence of the probability of gas ionization on the energy of the electrons incident on the gas molecules. At a pressure of 10^{-7} mm of mercury, the peak in the curve obtained at $V_g = 150$ volts is much less pronounced, whilst at 10^{-8} mm of mercury, the plot of log i_c against log V_g is almost linear over its central region. This last curve is primarily due to the residual effect created by the electrons released at the negative collector by X-rays produced at the positive grid.

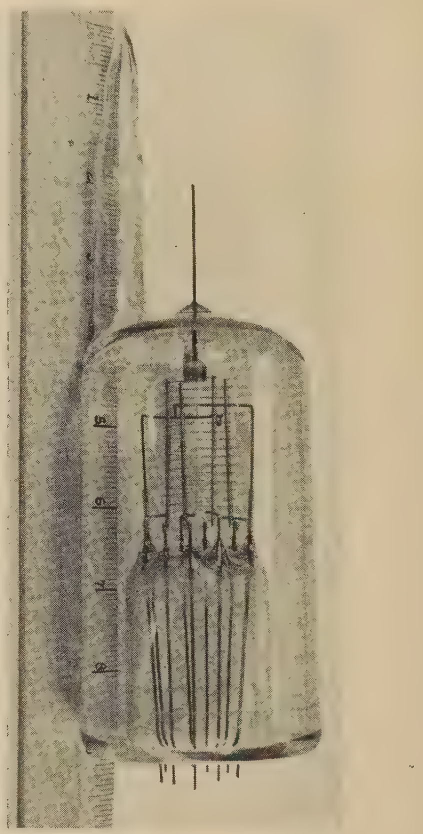


Fig. 3. A thermal ionization gauge of the Bayard–Alpert design

Two filaments: each made from 0·15 mm diameter tungsten wire formed into a V of total length $2\frac{1}{2}$ in.
Grid: wound from 0·006 in. diameter molybdenum wire; 1·5 in. long, 0·9 in. diameter, 10 turns per in.
Collector: tungsten wire, 2 in. long, 0·004 in. diameter.
Sensitivity using one filament: 13 μA mA^{-1} μ^{-1} with $V_g = 150$ V and $V_c = -30$ V.

In the modifications of the Bayard–Alpert design of ionization gauge due to Nottingham(12) the grid is enclosed at top and bottom with grid-like coverings and a second grid —a screen-grid—is installed around the electrodes. Nottingham points out that a positive ion has little chance of being collected directly at the central collector wire when the gas ssure is very low and so collisions of ions with gas atoms negligibly few. The ion therefore passes the collector e several times before collection. Meanwhile, the ion is ely to have a velocity component in the field parallel to collector wire; there consequently exists a probability of escape through the ends of the grid which encloses the ionization region, unless the end grid covers are used. Positive ions lost through the open ends of a grid, as in the Bayard–Alpert design, would not be recorded, but would escape to the glass walls of the gauge. The gas pressure indicated would therefore appear to be less than it actually was. The screen-grid introduced by Nottingham shields the gauge from the effects of wall charges. Maintenance of this screen-grid at a large negative potential also increases the average path of the electrons in the ionization region and, therefore, the ratio i_+/i_- at a given gas pressure.

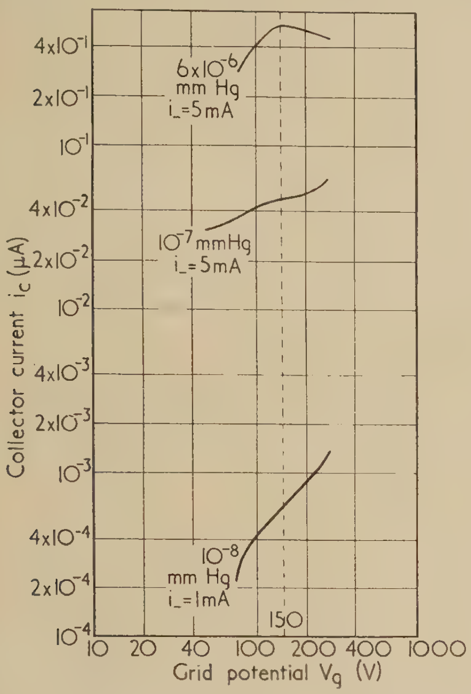
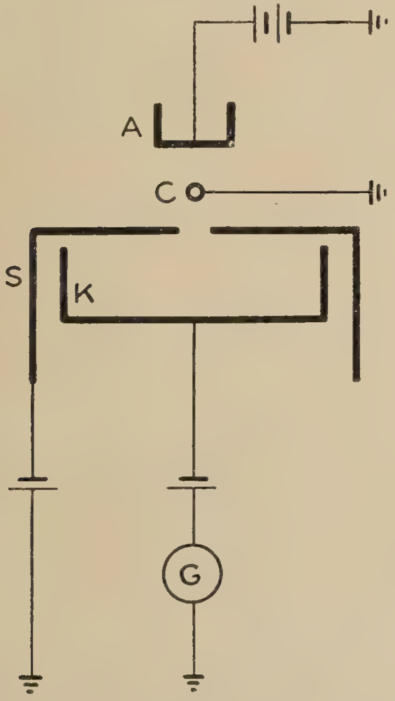


Fig. 4. Variation of collector current with grid potential at three different pressures for the ionization gauge BAR 507

Normal operating potential is 150 V.



[Reproduced from the *British Journal of Applied Physics*.]

Fig. 5. Principle of the Metson ionization gauge

Metson(13) discusses the design of an ionization gauge in which the effects of X-rays are reduced to a very low order by the use of a suppressor shield. Only a schematic diagram (Fig. 5) of this type of tube has been given so far. The use of the suppressor electrode should enable the lower limit of pressure measurement to be extended indefinitely.

ISOLATION VALVES FOR ULTRA-HIGH VACUUM SYSTEMS

To isolate the ionization gauge to be used as an ion pump from the contaminating action of the diffusion pump fluid at pressures below 10^{-7} mm of mercury, the gauge may be sealed-off from the pump by glass-blowing. Repeated experiments under more precisely controlled conditions can, however, be made if an isolation valve is employed and the gauge left connected. This valve obviously cannot employ the usual vacuum greases because they have significant vapour pressures, are liable to release occluded gases, and, most important of all, the valve must be able to withstand a degassing bake at about 450° C whilst under vacuum.

Alpert(14) devised a greaseless, all-metal ultra-high vacuum valve which can be baked at 450° C or more and, furthermore, can act not only as an isolation valve, but also as a very useful device for metering very small quantities of gas into a vacuum system. When closed, some of these valves had conductances as small as 10^{-11} l./s, whilst conductances of 5×10^{-9} l./s or less were still maintained after a year's use. Brown and Coyle(15) and Bills and Allen(16) have described modified forms of the Alpert valve. Decker(17) and Vogl and Evans(18) give designs of magnetically operated greaseless glass valves which function well as isolation devices on ultra-high vacuum systems, but cannot be used for metering small quantities of gas.

Modified forms of both the Alpert valve and the greaseless glass valve have been constructed and used in our experiments. It is possibly of more value here to describe these rather than to repeat the excellent descriptions given of the pioneer designs.

The modifications to the Alpert valve have been chiefly in the constructional materials used and in the soldering procedure employed. The principle of this type of valve is illustrated schematically by Fig. 6, whilst Fig. 7 shows the various parts of the assembly.

The action of this valve is simple. A cup made from oxygen-free copper (supplied by the Royal Mint Refineries) contains two $\frac{1}{4}$ in. diameter orifices. Kovar tubes are soldered into each of these holes; glass tubes joined to the Kovar tubes lead to the vacuum system. The conductance between these two tubes is reduced by inserting a conical Kovar nose-piece into one of the orifices. To ensure a vacuum-tight seal between the nose-piece and the copper cup, a flexible Kovar diaphragm is soldered between the barrel of the nose-piece and the rim of the cup. The nose-piece is driven forward by a differential screw driver mechanism (Fig. 8) which can be removed during baking. A wrench used to turn the square head to this driver mechanism is able—as in the original Alpert valve—to apply a torque of about 20 lb ft which, owing to the large mechanical advantage provided by the screw—enables a total force of about one ton to be exerted between the nose-piece and the wall of the orifice in the copper cup to close the valve fully. With such a large thrust, the Kovar nose is embedded so firmly into the softer copper that an excellent vacuum seal is effected.

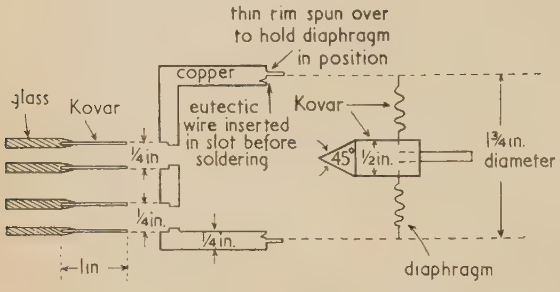


Fig. 6. Principle of an all-metal ultra-high vacuum valve of the Alpert pattern

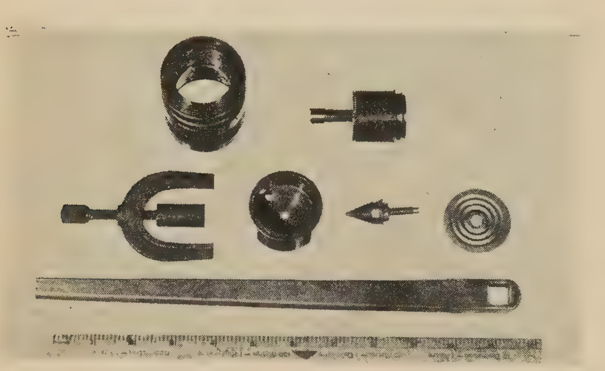


Fig. 7. Parts of an ultra-high vacuum valve of the Alpert design

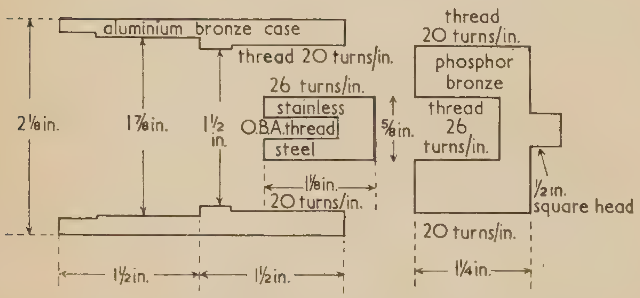


Fig. 8. The differential screw driver mechanism

When attached to the vacuum system, this valve has to withstand baking at 450° C. It is therefore essential to solder the valve components together at temperatures well in excess of this value. Furthermore, the metal parts and the solders must be scrupulously cleaned and must not contain volatile constituents. The soldering must not lead to oxidation of the metal parts; it must therefore be done in a hydrogen atmosphere, as was the case in Alpert's original work, or in a vacuum.

The outer rim of the Kovar diaphragm and the ends of the two Kovar tubes were copper-plated to prevent silver in the copper-silver eutectic solder used from causing cracking of the Kovar on inter-molecular penetration. The diaphragm was soldered to the copper cup and the Kovar tubes to the orifices in this cup by eddy-current heating in vacuum. Both seals were made in successive operations without breaking the vacuum. The use of an eddy-current heater coil was valuable in that it allowed the heating to be substantially localized in the region of the join to be effected. Thus, the glass tubes fused to the Kovar tubes were already in position but suffered no harm during the brazing. After cooling in vacuum, the valve was removed clean and free from surface oxidation.

The differential screw driver mechanism made was similar to that designed by Alpert, but was fabricated from phosphor bronze and aluminium bronze because stainless steel was not available. Two different alloys were used to prevent binding of the thread in use.

As in the Alpert valve, a "bake-out" clamp (see Fig. 7) was used to keep the valve in the open position during baking under vacuum when the driver mechanism was removed.

To prevent the closing torque applied by the wrench from straining the glass of the vacuum system, the ultra-high vacuum valve was firmly attached to a 6 in. length of 4 × 4 × ⅜ in. steel angle bolted to the steel frame of the vacuum system.

Our experience with this valve has by no means been so extensive as that reported by Alpert. It has served, however, as an excellent device for metering small quantities of gas into a vacuum system. Thus it has been found possible to let air directly from the atmosphere through this valve into an evacuated vessel isolated—by a greaseless glass valve—from the pumps and obtain reproducibly any desired pressure between 10^{-7} and 10^{-6} mm of mercury within the vessel. Experience indicates that this is certainly not possible if conventional needle valves are used.

Owing to delay in obtaining the metal parts for a valve of the Alpert type, most of our experiments on the ionization gauge as a pump have been conducted using a greaseless glass isolation valve. The design evolved is illustrated in Fig. 9. (During the course of this work, a similar design was described by Vogl and Evans.[18]) It employs a standard

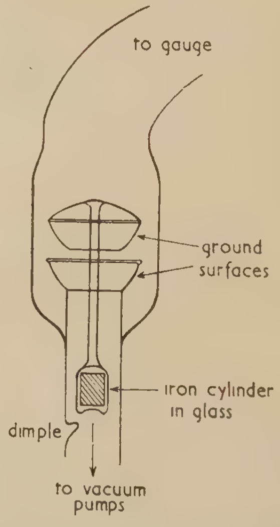


Fig. 9. The greaseless glass isolation valve

erical ground glass joint. The movable part of this joint be raised to open the valve by the action of an external seshoe magnet on a cylinder of iron sheet sealed within an ched glass tube. When open, the movable section is ed upon a dimple within the glass tubing to the vacuum nps (see Fig. 9).

uch a valve used without grease and made from Pyrex ss can be baked to 500° C when the vacuum pumps are rating. Though a very small conductance to gas flow is vided through the closed valve, this conductance is mani- ly much larger than for the Alpert design of valve. How- r, the closed valve serves to isolate an ion pump from the taminating action on the vacuum of the diffusion pump d at very low pressures. If the diffusion pump continues operate after closing the valve, the difference of pressure oss the valve will be, at the maximum, 10^{-6} mm of mercury practice. The mass of gas which can flow per second through valve with such a low pressure difference across it is gligibly small compared with the speed attainable by an ization gauge used as a pump.

Decker(17) reports that a valve of similar design was used isolate a manifold volume of one litre in which a pressure 10^{-9} mm of mercury was maintained for a week.

THE IONIZATION GAUGE AS A PUMP

The action of an ionization gauge as a pump has been estigated by several workers and, in particular, by hwarz(19) and Alpert.(7) A brief survey of the fundamental nsiderations involved is of value.

When an ionization gauge is operated normally, two distinct tions are responsible for clean-up of the residual gas in the uge. These are classified as chemical clean-up and electrical an-up. The first of these is due to the heated filament or thode; it takes place even though the grid and collector ltage supplies are absent. Electrical clean-up occurs only en these electrode voltages are present; it is due to the tion of the positive ion current. Molecules of the residual s are ionized on electron impact. The positive ions formed e attracted to the negative collector electrode. On arrival, ey give up their electrical charge and the neutral molecules sulting become trapped within the solid surface of the ctrode. The glass walls of an ionization gauge are also at near cathode potential(7) and also trap positive ions.

Following Alpert,(7) the rate of change of pressure p with ne t, i.e. dp/dt, will be given by

$$\frac{dp}{dt} = \frac{-S_E}{V}(p - p_E) \tag{1}$$

here S_E is the pumping speed of the gauge due to electrical an-up, V is the volume of the vacuum vessel concerned d p_E is the ultimate pressure attainable by this method of n pumping.

Experience with ionization gauges as pumps shows that p_E ay readily be less than one-hundredth of the initial pressure which the ion pumping action is started. For simplicity, erefore, p_E is neglected in equation (1).

Solving the simplified form of equation (1) gives

$$p = p_0 \cdot \exp\left(-\frac{S_E}{V}t\right) \tag{2}$$

here p_0 is the initial pressure at time $t = 0$.

Expressions of similar form may also be derived for the emical pumping action. For chemically inert gases, wever, electrical pumping only need be considered.

Alpert then assumes that every ion collected is permanently removed from the volume. This assumption has been criticized by Varadi(20) who quotes the experiments of Bloomer and Haine(21) in which molecules are apparently desorbed and diffused back from the collector surface. Disregarding temporarily these criticisms, and quoting Alpert, equation (2) may be expressed in the form

$$S_E = \left(-V\frac{dn}{dt}\right)/n \tag{3}$$

where n is the number of molecules per unit volume at the pressure p.

For a typical ionization gauge the positive ion current is 10^{-4} A at a pressure of one micron of nitrogen for an electron current of 10 mA. Assuming a linear relation between ion current and pressure at a given electron current, the ion current is therefore $10^{-(n+1)}$ A at a pressure 10^{-n} mm of mercury. Presuming that each positive ion carries a single electronic charge of $1 \cdot 6 \times 10^{-19}$ coulombs, this corresponds to a rate of removal of $(10^{19}/1 \cdot 6) \times 10^{-(n+1)}$, i.e. $6 \times 10^{18} \times 10^{-(n+1)}$ molecules per second, where the number of molecules per litre is $3 \cdot 2 \times 10^{19} \times 10^{-n}$.

Writing equation (3) in the form

$$S_E = -(dN/dt)/n$$

where $N = nV$ is the total number of molecules in the enclosure, and substituting the values quoted for a typical ionization gauge gives

$$S_E = \frac{-6 \times 10^{18} \times 10^{-(n+1)}}{3 \cdot 2 \times 10^{19} \times 10^{-n}} = 1 \cdot 9 \times 10^{-2}\ \text{l./s}$$

Alpert states that the pumping speeds which have been measured are a few litres per minute for chemically inactive gases—i.e. in agreement with the above calculation for an ionization gauge operated with an electron current of 10 mA —and that considerably greater speeds are obtained for active gases for which chemical clean-up will be effective as well as electrical pumping.

The molecules removed by ion pumping will accumulate on the ion collector and probably also on the glass walls of the gauge. These molecules will be retained by considerable surface forces if they form monomolecular layers. If it is assumed that the molecules are packed as closely together as possible, a monolayer of nitrogen will contain approximately 10^{15} molecules per square centimetre.

To investigate Alpert's claims regarding the speed of an ionization gauge as a pump, a Bayard–Alpert design of gauge (see Fig. 3) was isolated from a mercury diffusion pump with liquid air trap at a pressure of 7×10^{-7} mm of mercury by means of a greaseless glass valve of the design given in Fig. 9. The decrease of pressure with time subsequently recorded is shown in Fig. 10. The gauge had a sensitivity of 13 μA mA^{-1} μ^{-1} and was operated with an electron current i_- of 1 mA.

The total enclosed volume was 800 cm^3. The rate of fall of pressure, dp/dt, had a mean value of $1 \cdot 2 \times 10^{-7}$ mm of mercury/min for the first 7 min after which it fell off to $2 \cdot 5 \times 10^{-9}$ mm of mercury/min. The pressure decreased from 5×10^{-7} to 3×10^{-7} mm of mercury in $1 \cdot 8$ min, giving dp/dt equal to $1 \cdot 1 \times 10^{-7}$ mm of mercury/min at a mean pressure of 4×10^{-7} mm of mercury. The corresponding pumping speed S_E at this pressure is therefore given by

$$S_E = \frac{V}{p}\frac{dp}{dt} = \frac{0 \cdot 8}{4 \times 10^{-7}} \times 1 \cdot 1 \times 10^{-7} = 0 \cdot 2\ \text{l./min}$$

approximately

At an electron current of 10 mA, a figure of 2 l./min would be obtained. This agrees with Alpert's results.

At $1 \cdot 5 \times 10^{-7}$ mm of mercury, however, dp/dt was only $2 \cdot 5 \times 10^{-9}$ mm of mercury and the corresponding pumping speed was only one fifteenth of its former value.

Bloomer and Haine,$^{(21)}$ using a tungsten filament triode ionization gauge of a conventional design which was sealed-off from the pumps by glass-blowing, give similar results but where the initial pressure was somewhat greater than 10^{-5} mm of mercury. They denote the two distinct regions of their curve as A and B where A is the initial region of greater slope and B the region of smaller slope which begins at about one twentieth of the initial pressure and has a slope about twenty times smaller.

In discussing these results, Bloomer and Haine suggest the most likely explanation of the change of slope to be that gas is re-evolved from the sites to which it is cleaned-up, i.e. some of the gas molecules which reach the collector (and probably the glass walls) during pumping over the region B diffuse back into the evacuated space and reduce the pumping speed. Varadi,$^{(20)}$ in support of this contention, gives a modified equation for the electrical pumping speed to take into account the number of desorbed molecules. Furthermore, he questions Alpert's assumptions that every ion formed is captured at the collector.

Though our results agree with Bloomer and Haine's it is considered that Alpert's statements regarding the speed of the ionization gauge as a pump are justified. Thus the results given in Fig. 10 show that the speed is of the correct order of magnitude in accordance with the Alpert theory. Alpert reports, however, a continuous ion pumping action down to 10^{-10} mm of mercury, and even less. There seems to be little doubt that the disparity between our poor speeds at later stages of the pumping—which agree with the results of Bloomer and Haine—and Alpert's results are due to the use of too great an initial pressure. Thus, Alpert used a fractionating oil diffusion pump with a copper foil baffle$^{(22)}$ to prevent back-migration and baked the vessel containing the ion pump for six to eight hours as is the usual practice. His initial pressures before isolating the ionization gauge were almost certainly 5×10^{-8} mm of mercury or less.

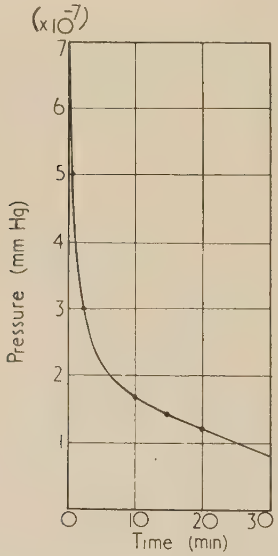


Fig. 10. Pressure against time curve obtained during ion pumping

Desorption of gas molecules from the surface where they have collected seems, therefore, to occur and reduce seriously the ion pumping speed eventually obtained if the initial pressure before ion pumping is above about 5×10^{-7} mm of mercury.

Assuming an ionization gauge operated at an electron current of 10 mA to give a rate of removal of $6 \times 10^{18} \times 10^{-(n+1)}$ molecules per second, as shown above, it is easily seen that the time taken to form a monolayer containing 10^{15} molecules on an area of 1 cm^2 is $1 \cdot 7 \times 10^{n-3}$ s at a pressure of 10^{-n} mm of mercury, i.e. 17 s if the pressure is 10^{-4} mm of mercury and $1 \cdot 7 \times 10^{6}$ s if the pressure is 10^{-9} mm of mercury. Alpert states that saturation of the gauge pump is indicated after about one hour if the pressure in it is maintained at 10^{-4} mm of mercury by the continual introduction of gas. This would indicate that the monolayers are formed not only on the thin wire ion collector of the Bayard–Alpert gauge (which has a surface area of only about $0 \cdot 1$ cm^2) but also on the glass walls, which would provide a total surface area of 100 cm^2 or more.

It is, however, difficult to reconcile these assertions with the fact that molecules of the gas will, as a result of their random kinetic velocities, form a monolayer in a time calculated from the kinetic theory as

$$t = (2.4 \times 10^{-6})/p \text{ second} \qquad (4)$$

for nitrogen (Bloomer and Haine$^{(21)}$) where p is the pressure in millimetres of mercury and assuming that the condensation coefficient is unity. At a pressure maintained continuously at 10^{-4} mm of mercury, a monolayer should form in only $2 \cdot 4 \times 10^{-2}$ s!

Application of equation (4) to the results shown in Fig. 10 and the similar ones of Bloomer and Haine is significant. In our experiment, the initial pressure of 7×10^{-7} mm of mercury decreased to $1 \cdot 7 \times 10^{-7}$ mm of mercury in ten minutes on operating the ion pump. Taking the mean pressure as $4 \cdot 5 \times 10^{-7}$ mm of mercury, a monolayer will form on a surface of 1 cm^2 due to the kinetic motion of the gas molecules in a time given by equation (4) as

$$t = (2 \cdot 4 \times 10^{-6})/(4 \cdot 5 \times 10^{-7}) = 5 \text{ s approximately}$$

It is not surprising, therefore, that with too great an initial pressure, the rate of removal of molecules by ion pumping eventually decreases seriously because saturated gas layers have formed on the collector and the glass walls, so that further molecules arriving are likely to diffuse back into the region undergoing evacuation. Even if a total collection area of 100 cm^2 is assumed, the time t is still only 500 s, i.e. of the same order of magnitude as the time of 600 s for which the ion pumping speed was in accordance with Alpert's calculations.

If, however, the initial pressure before ion pumping is reduced to 5×10^{-8} mm of mercury, then t becomes 50 s approximately for 1 cm^2, and ion pumping can proceed to very low pressures of the order of 10^{-10} mm of mercury without saturation effects—and therefore desorption of molecules from the collector surfaces—occurring.

A further interesting fact arises in discussing the formation of monolayers. Bloomer and Haine use equation (4) to point out that a pressure of about 10^{-10} mm of mercury is necessary to permit adequate time for measurements on uncontaminated surfaces of, for example, the work function. This demand for an exceedingly low pressure appears to be

-rated. A volume of one litre of a gas at a pressure of ^{n} mm of mercury contains $3{\cdot}2 \times 10^{19} \times 10^{-n}$ molecules. pressure of, say, 10^{-7} mm of mercury, only $3{\cdot}2 \times 10^{12}$ ecules will therefore be available per litre. Where are molecules to come from to form a contaminating layer 0^{15} molecules per square centimetre? There seems to be doubt that a pressure decrease from, say, 10^{-5} to ^{6} mm of mercury favours lack of contamination of mionic cathodes; experimental evidence for this is vided by the emission-type electron microscope. Such ct observations of contamination rates have not, so far s known, been made at ultra-high vacuum pressures, ever. It is probable that the issue is confused by the rtain effects of the walls of the enclosure. Gas molecules very likely to diffuse out of these walls, particularly if are of glass. Further experiments are undoubtedly ssary in discussing the formation and effects of mono- rs, particularly under ultra-high vacuum conditions.

THE OMEGATRON

n studies at low pressures it is often important to know nature of the constituents of the residual gas and their ial contributions to the total pressure. Such information ecessary in interpreting experiments on, for example, the usion of gases, the effects of gases on electrodes and, in icular, on thermionic and photoelectric cathodes, and the ence of impurities in gaseous discharges, as in ionic bility measurements. Much valuable work has been e in this connexion by means of the mass spectrometer,(23) this instrument is not only costly it is also difficult to gas it by baking to the extent demanded to obtain ultra- n vacua. The omegatron, due initially to Sommer, mas and Hipple,(24) has therefore been developed by ert and Buritz(25) to provide a sensitive means of recording ial pressures at a total pressure of 10^{-7} mm of mercury less. Though considerable difficulty is experienced in aining reliable and reproducible results with the omegatron, s likely, on further development, to prove a powerful rument in work at ultra-high vacua.

he principle of the omegatron is similar to that of the otron. It is well known that, in a cyclotron, a beam of itive ions is injected vertically near the centre of the gap veen a pair of "dee" plates across which a radio-frequency age is maintained. With a uniform magnetic field of density B acting in the direction perpendicular to the ne of the "dees," the ions receive successive additive elerations each time they cross the gap so that an expanding al path is produced provided that

$$\omega = Be/m \qquad (5)$$

re ω is the angular frequency of the radio-frequency ply and e is the charge on an ion of mass m.

n the omegatron (Fig. 11) electrons produced by the mionic filament F are accelerated through the aperture A in diameter) into the electric field-free space within a which is a 1 or 2 cm cube. (The box and plates DD' made from Advance sheet, 0·015 in. thick.) The defined n then emerges through an aperture A' in the opposite of the box and the beam current is recorded at an ron-collecting electrode (not shown). The plates DD' n the "dees" of the omegatron. Across them is main- ed a radio-frequency supply of about two volts peak e provided by a calibrated oscillator of which the fre- ncy can be varied at will. A magnetic field of flux density B provided by an external magnet is maintained parallel to the direction of the electron beam between A and A'. As in the cyclotron, the positive ions produced in the residual gas within the box will traverse a spiral path S of increasing radius in a plane perpendicular to the direction of the magnetic field. The spiral ion path terminates at a collector plate C inserted within a gap in the lower plate D'. The ion current recorded by a vibrating-reed electrometer is then a measure of the abundance of the gas ions with a specific charge e/m given by equation (5). Knowing the magnetic flux density B, the value of e/m, and hence the nature of the gas ion, is found for a recorded value of ω.

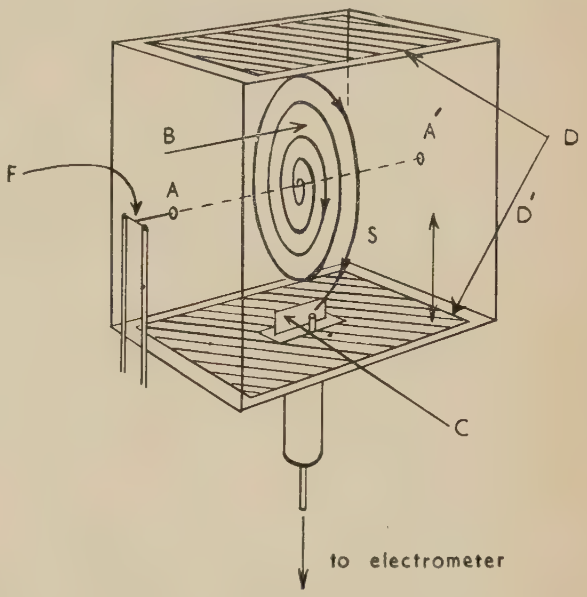


Fig. 11. Simplified diagram of an omegatron (after Alpert and Buritz(25))

Alpert reports that with a magnetic flux density of 2 100 G, the calculated value of ω is 3·2 Mc/s for an ion of mass number 1 and 32 kc/s for an ion of mass number 100, assuming that e is equal to the electronic charge.

Alpert and Buritz(25) give results (Fig. 12) for the ion collector current plotted against the frequency of the radio-frequency voltage across the "dee" plates for the case where

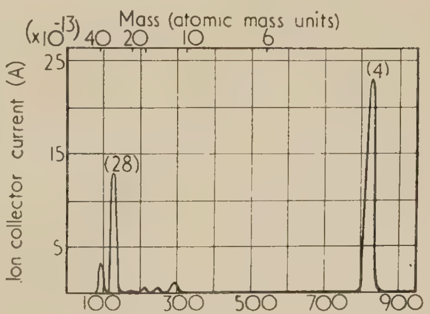


Fig. 12. Ion collector current against frequency of the radio-frequency supply

(Deviation from a linear relationship between mass number and frequency is due to non-uniform field distributions within the omegatron). (After Alpert and Buritz.(25))

the total pressure in the system is 10^{-7} mm of mercury, as recorded by an ionization gauge. The introduction of helium and nitrogen into the system gave positive identification of the frequencies corresponding to mass numbers of 4, 14 and 28. It is reported that the sensitivity of the omegatron to the total gas pressure is 10 μA mA^{-1} μ^{-1} when operated with a magnetic flux density of 2 100 G, an electron beam current of 4 μA and an accelerating potential on the box relative to the filament of 90 V. This sensitivity is comparable with that of a conventional ionization gauge.

FACTORS WHICH LIMIT THE LOWEST GAS PRESSURES OBTAINABLE IN A SEALED ENCLOSURE

Alpert and Buritz(25) report that the ultimate low pressure attainable in a glass system is set by diffusion of helium from the atmosphere through the glass walls. Despite the most rigorous degassing of the glass envelope and prolonged operation of an ion pump, ultimate low pressures below about 4×10^{-11} mm of mercury were not obtainable. In a series of carefully conducted experiments, it was shown that the ultimate was not due to the X-ray limit of a properly designed ionization gauge, nor to the vapour pressure of the tungsten filament of this gauge which was operated at 2 300° K. Furthermore, the residual rate of rise of pressure in a glass vessel sealed-off from the pumps was of the order of 3×10^{-11} mm of mercury per minute.

Support to their preliminary experiments that this limitation is due to atmospheric helium diffusing through the glass walls of the envelope was provided by Alpert and Buritz in experiments using an omegatron. The omegatron was run within a completely isolated glass envelope which had been initially evacuated to 10^{-9} mm of mercury. It was found that the height of the peak for the mass number 4 (i.e. for helium) increased linearly with time, but that the other peaks corresponding to other masses (chiefly at mass number 28 for molecular nitrogen) remained constant in height.

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The recording of electron diffraction patterns from single crystals using the Metropolitan-Vickers type E.M.3 electron microscope

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The design and construction of two additions to the Metropolitan-Vickers Type E.M.3 electron microscope which are useful in the study of the electron diffraction by single crystals are described. One addition, an adjustable rectangular diffraction aperture, is used to reduce the diffraction area selected at the specimen to a minimum, while the other, two pairs of deflector plates at right angles to which saw-tooth waveform voltages are applied, is useful in the accurate measurement of the intensities in single crystal patterns.

current work in this laboratory the electron diffraction m single crystals of synthetic polypeptides is being mined using a Metropolitan-Vickers Type E.M.3 electron roscope. These crystals are usually several microns long d from 200–1000 Å wide and are examined on a thin 200 Å) plastic or carbon supporting film. When the raction from these crystals is observed using either of the o circular diffraction apertures supplied with the E.M.3 (of meters 100 and 50 μ respectively) the incoherent scattering m large areas of the film surrounding the crystals is orded together with the discrete crystalline reflexions. e incoherent scattering causes a heavy background density the photographic plate which is inconvenient when urate intensity measurements are required. The design d construction of an adjustable rectangular aperture which luces to a minimum the area of the supporting film selected the specimen are described in section 1 below.

There is in general no simple relationship between the ensities of the reflexions in single crystal patterns and the ckening of the photographic plate used to record them. gh intensity reflexions are recorded as spots of large meter and low intensity reflexions as spots of small meter. The relationship between spot diameter and ensity has been used with some success by Cowley, Rees d Spink(1) for the measurement of the intensities in single stal patterns from paraffin. However, it is more con- nient and more accurate to apply the method of Cowley(2) the measurement of spot intensities by which the diffracted ctron beams are deflected by two low frequency voltages th saw-tooth waveforms acting at right angles. The spots recorded on the photographic plate as rectangles all of ich have the same area. The intensities of the reflexions proportional to the optical densities of the rectangles ove the background density. The insertion of a suitable flecting system into the E.M.3 is described in section 2.

1. THE ADJUSTABLE RECTANGULAR APERTURE

The rectangular aperture system is shown in Fig. 1. It nsists essentially of four phosphor-bronze jaws moved dependently by four $\frac{1}{4}$ in. diameter rotary shafts operating rough conventional vacuum seals in the side of a brass ate of thickness $\frac{5}{8}$ in. The microscope column is raised om its normal position by the insertion of the brass plate form part of the column. It is necessary to make a pump- g connexion at the rear of the plate and to seal the pumping rt in the section holding the diffraction aperture supplied with the microscope which is out of alignment with the pumping line. The pumping line to the specimen chamber must also be lifted to compensate for the raising of the column. Efficient evacuation of the column is ensured by four $\frac{3}{16}$ in. diameter pumping holes which surround the rectangular aperture and which are outside the region of the electron beam. The rotary shafts act through threaded holes in the brass plate (40 threads/in.) and are terminated by ball ends integral with the shaft each of which engages in a slot at the rear of a movable jaw. The jaws are rectangular in section with dimensions $1\frac{1}{4} \times \frac{1}{2} \times \frac{1}{16}$ in. The four ends of the jaws which form the aperture are chamfered at an angle of 45° and the leading edges carefully lapped to a smooth finish. Two of the jaws move in a slightly lower plane than the other two but the edges of the two pairs of blades are oppositely ground to make the aperture as nearly planar as possible. Each jaw moves in a groove under the action of a phosphor-bronze spring tongue tightly screwed to the base plate. Because of the positions of the specimen stage movement controls the four shafts which move the jaws are not symmetrically disposed with respect to the column. The asymmetric placing of the shafts with respect to the pumping port is shown in Fig. 1. The vacuum seals between the brass

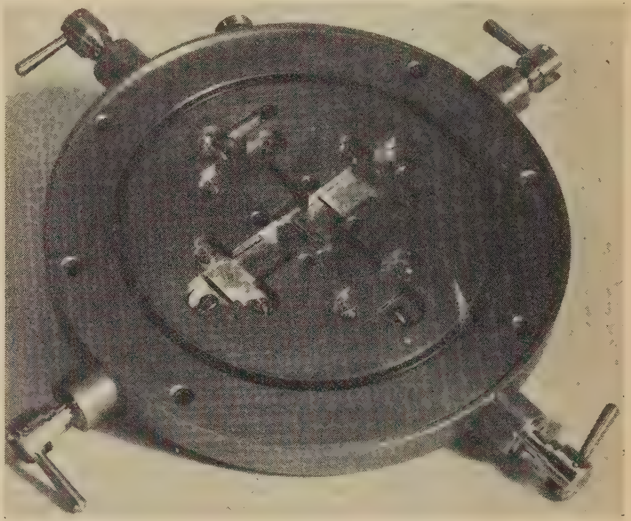

Fig. 1. The adjustable rectangular aperture system

carrier plate and the microscope column are made with O-rings. The studs which originally secured the diffraction aperture system fitted to the microscope were replaced by longer ones to accommodate the brass plate. When not required the jaws may be moved outside the region of the beam exposing a central circular aperture of $\frac{1}{4}$ in. diameter. The rectangular aperture is easily adjustable to form a square aperture of area $(10\ \mu)^2$ corresponding to a selected area at the specimen of about $(4000\ \text{Å})^2$.

2. THE DEFLECTOR PLATE SYSTEM

The deflector plate system is shown in Fig. 2. It consists of two pairs of parallel rectangular stainless steel plates with dimensions $\frac{5}{8} \times \frac{5}{8} \times 0{\cdot}025$ in. having narrow projections by which they are riveted to an insulated base plate. The overall engths of the pairs of deflector plates from the base plate are respectively $1\frac{5}{8}$ and $\frac{7}{8}$ in. The insulating base is covered by a phosphor-bronze cap down the centre of which runs a removable phosphor-bronze tube of internal diameter $\frac{7}{32}$ i which prevents electrons being scattered away from th deflector plates and allows easy cleaning. One of each pa of parallel deflector plates is earthed while the other tw plates have phosphor-bronze spring contacts to which th deflecting voltages are applied. The cap of the deflector un is a push fit into a $1\frac{1}{8}$ in. diameter hole in a brass plate ($\frac{1}{2}$ in thick) which is inserted between the objective lens and th intermediate alignment stage of the microscope to form par of the microscope column. The microscope is again raise above its normal height and the pumping line to the specime chamber has to be raised correspondingly. The deflecto plates project below the level of the brass plate when th apparatus is inserted into the column and the separation o the plates ($\frac{7}{16}$ in.) is such that they fit inside the sho cylindrical mu-metal screen (diameter $\frac{7}{8}$ in.) which passe through the bellows at the intermediate alignment sectio The deflecting voltages are applied through glass-to-me seals inserted in the side of the brass plate and by way o two stiff insulated rods which pass through the plate a engage in the spring contacts on the two deflector plates t which the voltage is to be applied. The vacuum seals wi the microscope are made with O-rings. The two unsyn chronized saw-tooth waveform voltages are convenien obtained by passing the outputs from two low frequen square-wave signal-generators through simple series capacito resistance integrating circuits and utilizing the voltage wav forms across the capacitors. For normal microscopy t two insulated deflector plates must be earthed. At t laboratory, for microscopy, an objective lens limiti aperture system which fits between the specimen stage a the objective lens is used which does not require the remo of the deflector plates.

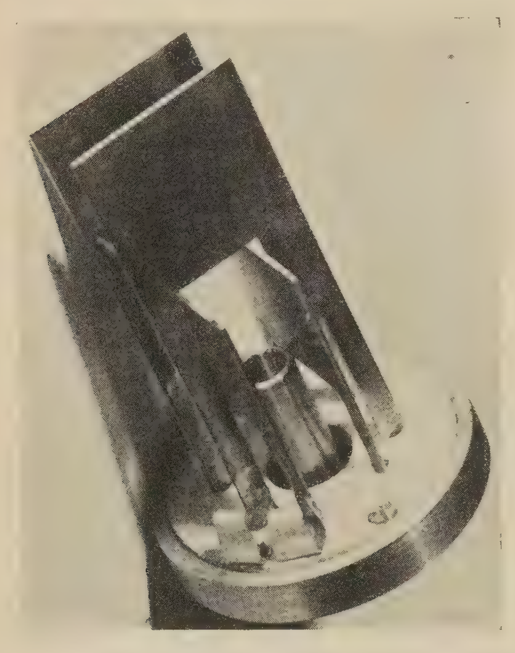

Fig. 2. The deflector plate system

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A half-silvered mirror tangentimeter

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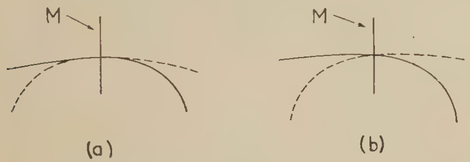
In order to measure the slope of a curve at a given point, a vertical half-silvered mirror is set perpendicular to the curve by rotating it until the reflexion of one half of the curve in the mirror coincides as nearly as possible with the other half of the curve, seen through the mirror. The instrument is fitted with both a tangent scale and a degree scale and, in favourable circumstances, is capable of an accuracy of ±0·25°.

number of devices have been described for obtaining the pe of a graph at a given point.(1–7) One well-known thod involves rotating a vertical mirror about the given nt until it is perpendicular to the curve, as judged by the itinuity of one half of the curve with its mirror image. In tangentimeter described below this method has been proved by using a thin half-silvered mirror instead of the ial completely reflecting mirror. The setting of the half-ered mirror perpendicular to the curve is accomplished rotating the mirror about the given point until the reflexion each half of the curve in the mirror coincides as nearly as ssible with the other half of the curve itself, seen *through* mirror. (In general, owing to lack of symmetry of the ve, apparent coincidence will be obtainable only over a nparatively short portion of the curve on either side of the rror.) A person with normal sight is easily able to check ncidence on both sides of the mirror at the same time by cing his head symmetrically above the mirror and using th eyes together. Both the left- and right-hand halves of curve itself can then be seen by both eyes (either directly *through* the mirror), but their reflexions in the mirror can ly be seen by the left and right eye respectively. The view is obtained is shown in Fig. 1 which illustrates both correct d incorrect settings of the mirror *M*.



(a) (b)

Fig. 1. Field of view illustrating (*a*) correct setting of the mirror *M* perpendicular to the curve, and (*b*) an incorrect setting corresponding to a 5° rotation of the mirror *M* from the correct setting

The full line represents the original curve and the dashed line its image after reflexion in the mirror *M*.

CONSTRUCTION

The details of construction of the tangentimeter are shown Fig. 2. The base *B* consists of a cast iron ring fitted with ee rounded feet *F* enabling the instrument to be moved oothly over the curve to be measured. The Perspex scale consists of an annular ring mounted on a ball race so that can be rotated with respect to the base. The remainder of apparatus, the mirror unit *U*, consists primarily of a tical half-silvered mirror *M* and an annular Perspex ring carrying four hair-lines, *H* and *H′*, moving over the scale *S*. e half-silvered mirror itself was prepared by depositing a table film of aluminium on one side of a thin (0·15 mm) glass plate by vacuum evaporation. The mirror unit is mounted on a second ball race for ease of rotation with respect to the base and carries two 4 V bulbs *I* to provide symmetrical illumination for the curve. The instrument is fitted with a large convex lens *L* (focal length 22 cm) which considerably increases the accuracy and ease of operation of the instrument.

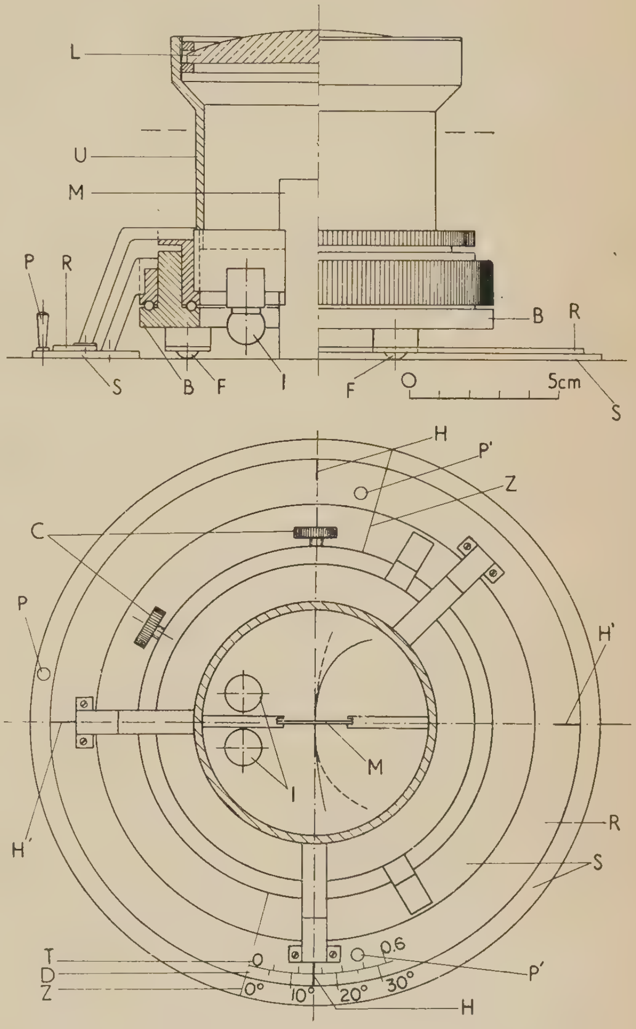


Fig. 2. Side view, section and plan of tangentimeter

(Only part of the scales are shown in the figure, the subdivisions also being omitted for the sake of clarity.)

OPERATION

The instrument is placed on the paper so that the mirror *M* is approximately perpendicular to the curve, the centre of the mirror coinciding with the point at which the slope is to be measured. The scale *S* is then rotated by means of the pin *P* until its zero line *Z* lies parallel to the *x* axis, when it is clamped by one of the locking screws *C*. This operation is facilitated by a number of auxiliary lines on the scale (not shown in the diagram) which are either parallel or perpendicular to the zero line. The mirror unit *U* is then rotated by means of the pins *P'* until coincidence (as described above) is obtained. The slope of the curve in degrees can now be read off on the degree scale *D*, using the main hair-lines *H*, while the tangent of this slope (dy/dx) can be read off directly from the tangent scale *T*, again using the main hair-lines *H*. If the cotangent of the slope (dx/dy) is required, it too can be read off from the tangent scale *T*, using the two auxiliary hair-lines *H'*.

PERFORMANCE

Under favourable conditions, the instrument is capable of an accuracy of ±0·25° (corresponding to one quarter of a scale division), but such high accuracy is usually of no significance owing to drawing errors present in most graphs. The accuracy of the instrument is in general greater tha that of the curve being measured, though cases arise (e.g curves having particularly small radii of curvature or havin a point of inflexion) when the accuracy of the instrument reduced considerably. The presence of two hair-lines o opposite sides of the scale provides a possibility of checkin the adjustment of the instrument; if necessary, whe the highest accuracy is required, the average value o the two readings can be taken. Measurements can be carrie out rapidly and the instrument can be used continuousl without causing eye-strain.

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A sensitive electronic strain gauge

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A sensitive strain gauge which was developed for investigating the electromechanical properties of ferroelectric barium titanate is described. It responds faithfully only to displacements occurring fairly rapidly, i.e. in less than about 1 s. The lower limit of its response time is determined mainly by the mechanical system coupling the specimen to the gauge, and is of the order of 1 ms. The limit of sensitivity is about 10^{-7} cm, but the sensitivity is variable over a wide range and absolute calibration is possible. The design allows the specimen temperature to be controlled over a range −150 to +200°C.

The strain gauge to be described was developed as a means of investigating the electromechanical properties of ferroelectric barium titanate. The gauge is normally used dynamically, i.e. the strain is observed when an alternating electric field is applied to the specimen, the main advantage of this method as compared with the "step-by-step" method previously used by Caspari and Merz(1) being the rapidity with which results are obtainable. Use is made of an electronic circuit that is sensitive to small capacitance-changes, and, by arranging for the specimen-strain x to displace one of the parallel plates of an air condenser which forms a part of the detecting circuit, the strain is translated into an alternating e.m.f. Observations are made by applying this e.m.f. after amplification to the Y-deflecting plates of a cathode-ray tube, while simultaneously an e.m.f. representing either the electric field E applied to the specimen, or its electric displacement D is applied to the X-plates. Thus one displays on the cathode-ray tube the $^x/E$ or $^x/D$ loops characteristic of the specimen being studied. An example of such a set of loops is shown in Fig. 1, for which the specimen was a twinned crystal of barium titanate.

MECHANICAL DESIGN

Both the air condenser mentioned above and the detecting circuit are situated remotely from the specimen, so that the temperature of the latter may be varied by inserting it into a temperature-controlled enclosure. To this end a system of seven quartz tubes is used, the tubes projecting horizontally from the main body of the strain gauge, as shown in the

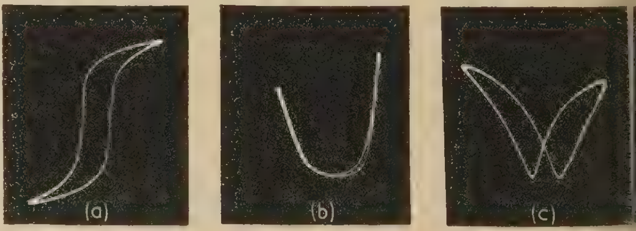

Fig. 1. Electromechanical response of twinned barium titanate crystal

(*a*) Electric displacement/electric field (D/E) loop. (*b*) Strain/displacement (x/D) loop. (*c*) Strain/field (x/E) loop.

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matic diagram of Fig. 2. Three of the tubes serve only pport the remainder, and for clarity they are omitted the diagram. Of the other tubes three comprise a rating device, while the one central tube serves as the t link between the specimen and the moving plate of the lenser. Seen in cross-section the first six tubes are

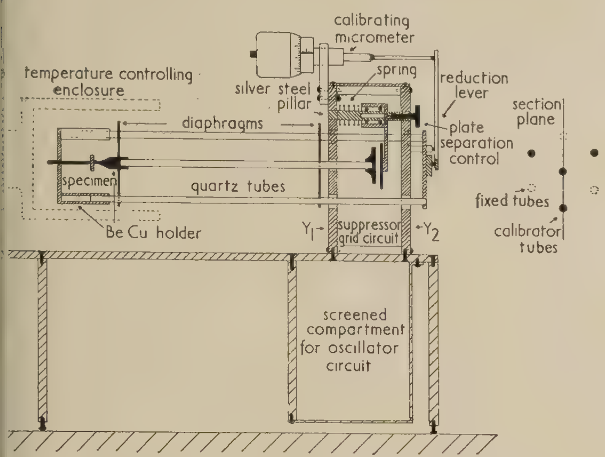

Fig. 2. Strain gauge mechanical design

lly spaced round the circumference of a circle, with the calibrator tubes interspacing the three supporting tubes. latter are cemented into the vertical brass plates Y_1 and while the former, being supported elsewhere, pierce these s without hindrance. The central tube also pierces Y_1 rder to reach the detecting circuit, enclosed between Y_1 Y_2.

he free tubes are supported by two pairs of beryllium–er diaphragms, which have been described elsewhere.(2) type is used to link the calibrator tubes with the support-tubes, while another type is used to link the central tube he calibrator tubes. These diaphragms allow the tubes move only parallel to themselves, and the maximum lacement is about 0·3 cm in either direction. The hragms were etched with nitric acid from sheet llium–copper, 0·13 mm thick, and they were sub-ently subjected to the appropriate heat treatment.

he specimen is held between two beryllium–copper orts, normally terminated by spherical balls 0·15 cm in eter. One of these supports is attached to the central , while the other forms a part of a terminating link een the calibrator tubes. By the spring action of the hragms the two supports are always held lightly in act with one another, so that any motion imparted to calibrator tubes is also imparted to the central tube. s calibration may be achieved by noting the response of electronic circuit when the calibrator tubes are displaced ugh a known distance. In practice, displacements of the rator tubes are effected by a micrometer bearing on a nd terminating link at the end remote from the specimen.

hen considering the electromechanical effect the calibrator s may be regarded as fixed, whereas the central tube, g constrained only by the diaphragms, can be set in ion by the electromechanical response of a specimen. s whenever the specimen is strained there occurs a esponding change in the condenser-plate separation, and resulting capacity change is then detected by the electronic it. The sensitivity of the strain gauge so formed is rolled by varying the mean separation of the condenser plates, and in order that the sensitivity may be controlled irrespective of the specimen thickness the "fixed" condenser plate is mounted on a carriage propelled by an external knob. The carriage is supported by a kinematic slide of ball-bearings running on silver steel pillars, and its motion is perfectly smooth and without backlash. The fixed plate may be adjusted to be parallel with its counterpart.

It is possible for the electromechanical response of a specimen to excite resonances in the system of quartz tubes and other parts of the apparatus; and, since the excitation of any one of the resonances may cause entirely spurious results to be observed, the existence of these resonances sets an upper limit to the frequency of the alternating field that may be applied. The longitudinal resonance of the central tube and its condenser plate is not the most troublesome, as it occurs at a comparatively high frequency, but resonances occur at much lower frequencies due, apparently, to lateral motion of the tubes and to the finite stiffness of the calibrating system. The response was improved by adding damping in the form of cotton wool inserted between the tubes, and the lateral motion controlled to some extent by selecting tubes with only small departures from straightness.

In general the waveform of the vibration representing the electromechanical response of a specimen will contain many harmonics of the applied frequency, and resonances may therefore be excited even though a frequency well below that of the lowest resonance is being used. The frequency of the first of the resonances is approximately 600 c/s, and it is found that for average specimens the highest usable applied frequency is of the order of 100 c/s, while for specimens having a particularly non-linear response the uppermost frequency may be only 5 c/s.

The mean separation of the condenser plates was rendered largely independent of thermal expansions by inserting, as part of the central tube, a piece of beryllium–copper equal in length to the beryllium–copper holder that terminates the calibrator tubes. Thus, although in the present application it is not required to operate the strain gauge statically, it would be possible to do so. Electrical connexions with the specimen are made by leads taken down the centre of two of the supporting quartz tubes, and one of the diaphragms provides the required connexion with the specimen holder attached to the central tube.

Temperature control in the range −150 to +200° C is achieved by enclosing the specimen and its supporting tubes in a hollow copper cylinder, the temperature of which is determined by that of a massive copper block in thermal contact with it. The latter may be either cooled by partial immersion in liquid oxygen or heated electrically. It is important that as little microphonic interference as possible be introduced into the strain gauge by the temperature-controlling system, and therefore a flow of gas, as distinct from a stirred liquid, is used to maintain thermal equilibrium in the specimen enclosure.

THE ELECTRONIC CIRCUIT

The electronic circuit employed is a development of one previously described by Alexander.(3) The operation of this circuit depends on a rapid change that occurs in the anode voltage of the octode class of valve when either of the two parallel resonant circuits connected to certain of its grids is detuned from a common resonant frequency. In Alexander's circuit, which is shown in Fig. 3, an oscillator is operated between the first and second grids, and a tunable oscillatory circuit (LC) is connected to the fourth grid. Connected in parallel with the circuit-tuning capacitor C_1 is a second small capacitor C_2, and the value of C_2 is modulated by the action of the motion being studied. In this way small mechanical movements are translated into changes in the resonant frequency of the tuned circuit, and the octode circuit in turn translates these frequency changes into anode voltage changes. Oscillator frequencies of about 20 Mc/s are used.

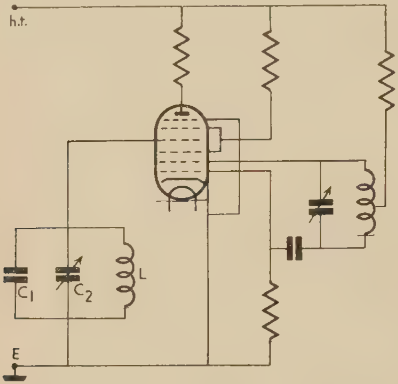

Fig. 3. Alexander's circuit

When the resonant frequencies f_1 and f_2 of the two oscillatory circuits are set to widely different values the average anode voltage has a steady value irrespective of whether f_1 is greater or less than f_2. Maintaining f_1 constant and varying f_2 in the range of frequencies that includes f_1, the anode voltage V_a is found to change in the manner of Fig. 4. In the region where f_1 is approximately equal to f_2 the change of voltage with frequency is almost linear, and the rate of change has a maximum value. Alexander gives the circuit sensitivity as 90 V/pF change in C.

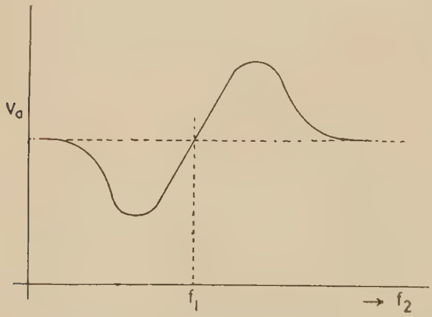

Fig. 4. Variation of anode voltage with tuning in Alexander's circuit

When this circuit is used to form a strain gauge the smallest detectable strain is that which produces a signal at the octode anode that is somewhat greater than the random noise level. This minimum detectable strain thus depends on the design of the measuring condenser, which will now be considered. If the plate area is A cm^2 and the separation l cm, the capacitance is given by

$$C = A/4\pi l \text{ cm} \tag{1}$$

Hence

$$\delta C = -(A/4\pi l^2)\delta l = -C(\delta l/l) \tag{2}$$

For the greatest sensitivity it thus appears that A should be made as large as possible and l as small as possible. However, C must not be made too large, or the Q of th tuned circuit is liable to be reduced, resulting in a reduce sensitivity. There are also independent reasons why A cann be increased and l reduced indefinitely. The larger A made the greater is the mass of the moving plate and t worse the speed of response. For linearity of response t condition $\delta l \ll l$ applies, but in some experiments the ratio maximum strain to minimum strain to be detected is as hig as 2000. It is then convenient to make l much larger tha the maximum displacement contemplated in order to avoi frequent readjustment and recalibration. Very small gap might also result in drifts in sensitivity owing to incomple compensation of the thermal expansion of the tubes, and i practice a minimum value of l of 5×10^{-2} cm was adopte together with a value of 5 cm^2 for A.

The noise output at the anode of the octode in Alexander circuit was found to be high, amounting to about 600 μ r.m.s. in a band width of 10^4 c/s. With the conden parameters adopted, a displacement of 10^{-7} cm should th be detectable with a signal-to-noise ratio of 2·7. This w regarded as inadequate, and a number of circuit modificatio were tried experimentally, and two important conclusio were reached.

(i) The most serious noise component, which is pres only when the circuit is tuned, results from random frequen fluctuations arising in the oscillator circuit. A reduction i the noise level by a factor of about five was achieved by us an oscillator circuit that has been described by Gouriet(4) a being particularly stable, and by using a quartz crystal t control the frequency of this oscillator.

(ii) That component of the noise which is present whet or not the circuit is tuned can be reduced by a factor of ab two by employing two valves, a triode and a pentode, i place of the octode. As shown in Fig. 5 the triode (which i practice is a triode-connected pentode) is then connected a an oscillator, and it is of some importance that the particu circuit arrangement used allows the signal to be tapped fro the cathode, so obviating the noise that is inherent in a hig impedance output. In the pentode, which now becomes th "mixer," the suppressor grid is used as a second control gri

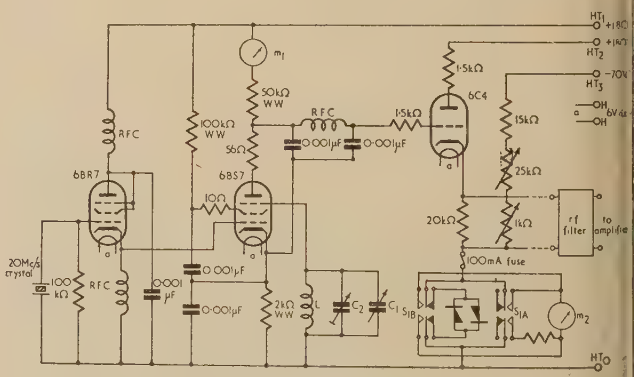

Fig. 5. Strain gauge circuit

yet no loss of sensitivity arises, the sensitivity under optimu conditions being approximately 120 V/pF.

The components corresponding to the circuit of Fig. except for m_2 and its associates, are all mounted in th enclosures shown in Fig. 2, and it will be noted that a catho follower type 6C4 is included to feed the signal along screened cable.

Having reduced the electrical noise and increased th tivity to this extent, it was found that microphonic ference became dominant when attempts were made to he full sensitivity. Both airborne and structure-borne anical disturbances can modulate the impedance of the d circuit giving a spurious output. Most sensitive to ference is, of course, the capacitor C_1, but appreciable ference also arises in other parts of the circuit. To ce these effects the apparatus is mounted on shock-rbing supports, and is also enclosed in a sound-proof Further, the valves, which were themselves selected to the least noise and microphony, are mounted on specially ble rubber supports; and the tuned circuits are so rigidly tructed that they possess no mechanical resonances in the uency range used.

novel shock-absorbing system has been used, and d to be very effective. A certain measure of protection ven by using a slate-topped bench that is supported by rete pillars set in the frame of the building. Above this two further slate slabs, each weighing about 12 kg, and separated from the one below by four football bladders, ally inflated. The natural frequency of vibration of this m is less than 2 c/s, and a high degree of damping is ided by the rubber football bladders.

ith these precautions the total noise, including that due nicrophony, amounted to about 200 μV under quiet litions, so that displacement of 10^{-7} cm could now be sured with a signal-to-noise ratio of about eleven.

further improvement is possible in cases where noise be reduced by restricting the frequency response of the em with a filter. The frequency of the voltage applied to specimen is usually less than 50 c/s while much of the gy of the noise spectrum lies above 1 kc/s. Some of the eforms contain steep transients which would be distorted uch a filter, and for this reason no filter was used in the al investigation of electromechanical effects in barium ate. In some cases where the applied frequency could s low as 2 c/s, however, a filter could be used and dis-ements of the order of 10^{-8} cm measured.

AMPLIFIER AND POWER SUPPLIES

order that the e.m.f. representing the electromechanical ct may be displayed on the cathode-ray tube, it is necessary mplify to a suitable degree the output of the strain-gauge uit. It is essential that the amplifier used should be free n phase error in the frequency range of 5 c/s to 10 kc/s, to attain the lower limit very long time constants would required if a capacitor-coupled amplifier were used. In event there would be a tendency for the amplifier to ome blocked temporarily whenever too large a voltage applied to the input, and to reduce this tendency the olifier is, as far as possible, direct-coupled. It is also ntial that such noise and hum as is introduced by the olifier should be negligible compared with an input signal 200 μV. It was found that by using type EF 86 valves as input pair, a satisfactorily low noise-level was attained. h hum and the effect of small variations in the supply entials were greatly reduced by using a balanced-amplifier nique with differential input.

he required range of voltage amplification, as determined the anticipated variation among the electromechanical cts to be studied, extends from 5×10^3 to 2×10^6. To cover this range effectively two gain controls, arranged in such a way that the early stages of the amplifier need never be overloaded, are provided. Measurement of the gain is facilitated by the use of a standard square wave signal source and attenuator, by means of which a signal of known amplitude may be injected at the amplifier input.

Carefully stabilized power supplies are used to operate the equipment, and the heaters of all valves are supplied from a stable d.c. source.

CALIBRATION

The strain gauge is calibrated by noting the change that is effected in the cathode current of the cathode follower triode V_3 by a known micrometer displacement. To measure accurately the change in cathode current, i.e. δI, a high-grade meter m_2 having a full-scale deflexion of 250 μA is used in conjunction with a suitable back-off supply. This meter is mounted remotely from the strain gauge, but a less sensitive meter, m_1, observed when tuning the circuit, is mounted alongside the tuning capacitor C_2 (see Fig. 5). The meter m_2 can be used normally, switched out of circuit, or protected by a double rectifier shunt by means of the three-position key S_{1A}, S_{1B}.

When the circuit sensitivity is at a maximum it is found that the greatest change that can be made in the capacitor-plate separation without departing from the linear portion of the strain gauge characteristic is about 2×10^{-3} cm. However, the calibrating micrometer is graduated only to 5×10^{-4} cm, so that to obtain an accuracy of 1% the total micrometer displacement would have to be 5×10^{-2} cm. To overcome this discrepancy a lever giving a reduction ratio of 20 : 1 is used to couple the micrometer to the calibrator tubes. The most important feature of this lever, which is of a type described by Clay,(5) is that its ratio remains unaltered throughout its range of action.

If r is the lever ratio and δT the observed displacement of the micrometer, we may write $r(\delta I/\delta T)$ for the slope of the strain gauge characteristic. Further, if V_x is the amplifier output voltage, G the amplifier gain, R the cathode load resistance of the triode and t the specimen thickness, it follows that the specimen strain is given by

$$x = (V_x/GRt)\,(\delta T/\delta I) \qquad (3)$$

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The optimum design of quarter-squares multipliers with segmente characteristics

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A general discussion of quarter-squares multiplication shows that there are no serious disadvantages in the use of non-linear units with monotonic characteristics. The total truncation error, due to the approximation of the ideal non-linear characteristics by a finite number of equal linear segments, is evaluated. Formulae are deduced for optimizing a multiplier's performance in specified applications by using segments of unequal lengths. In typical cases savings of between 5 and 20% in the number of segments needed for a given accuracy can be achieved: the optimum distributions of segment lengths differ only slightly from the uniform distribution with equal segments.

1. INTRODUCTION

The increasing scope of present-day electronic analogue computing and of the corresponding simulation and control-system techniques has led to a demand for electronic multipliers capable of forming an output voltage accurately proportional to the product of two time-varying input voltages. The desiderata are: accuracy, large bandwidth, simplicity, reliability and low cost. The principle of quarter-squares multiplication based on the identity

$$\tfrac{1}{4}[(x+y)^2-(x-y)^2] \equiv xy \qquad (1)$$

is now well known. In spite of many other proposals and designs$^{(1)}$ multipliers utilizing this principle represent, for many purposes, the most satisfactory compromise$^{(2)}$ between the conflicting requirements listed above. Reliability and large bandwidth may be obtained by approximating the required non-linear characteristics by a series of linear segments generated by using biased diodes to switch the gain of an amplifier.$^{(1,2,3)}$

The limiting accuracy of this type of multiplier is determined by N the number of segments used to approximate the ideal characteristic over the required range. However, for given N, the segments can be of differing lengths. The question then arises of finding the optimum distribution of segment lengths. For example, it seems intuitively obvious that if the absolute error in the multiplier output is to be especially small when both inputs are small (in order to keep the *proportional* error low) then the segments should be shorter in the central part of the characteristics. The present note attempts to give a quantitative answer to this problem.

In Section 2 the general principles of operation are considered and it is shown that there is no great advantage to be gained by using a symmetric parabolic characteristic. The nature of the approximation of a quadratic curve by a straight segment is discussed in Section 3 and the truncation errors in the output of a multiplier using non-linear units with segments of equal length are evaluated.

The advantages to be gained by using unequal segments are assessed in Sections 4 and 5, where formulae for determining the optimum distributions are presented.

2. PRINCIPLES OF OPERATION AND THE NON-LINEAR CHARACTERISTICS

A quarter-squares multiplier consists basically of two similar non-linear units having, ideally, quadratic input-output characteristics for some specified range of inputs. Thus we may suppose that for an input w the output of non-linear unit is

$$W = f(w) = aw^2 + bw + c + e(w)$$

where a, b, and c are constants and where $e(w)$ represents error or deviation from the ideal characteristic. The err $e(w)$ will be small only within the operating range of non-linear unit: without loss of generality this may be taken

$$|w| \leqslant l$$

which implies that inputs must be confined within limits $\pm l$.

To obtain the product of two inputs x and y to a multip the sum

$$z = f(x+y) - f(x-y) - 2by$$

is formed. This reduces to

$$z = 4axy + e(x+y) - e(x-y)$$

i.e. to the required product term $4axy$ plus error terms whic will be small when

$$|x+y| \leqslant l \quad \text{and} \quad |x-y| \leqslant l$$

These last equations describe a diamond shaped "va region" in the (x, y) or input-plane (see Fig. 1). Only if th combination of inputs (x, y) falls within this valid regio will the multiplier function without gross error.

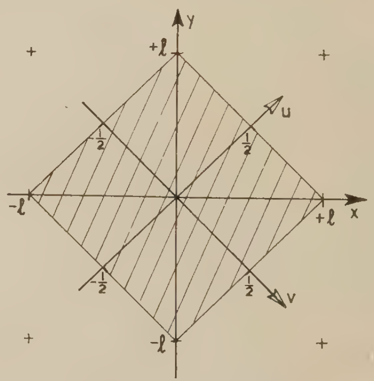

Fig. 1. The valid region (shaded) in the (x, y)- or input-plane of a quarter-squares multiplier

The auxiliary variables u and v are defined in Appendix B.

In practice the two non-linear units will not be identica however, the product may still be obtained by forming

$$z = f_1(x+y) - \alpha f_2(x-y+\delta) - 2b_1 y - \varepsilon \qquad ($$

djusting b_1, the factor $\alpha(\simeq 1)$ and the small constants ε to cancel the unwanted terms. Neglecting the factor e total (absolute) error in the multiplier output is

$$E = e_1(x + y) - e_2(x - y) \tag{8}$$

e maximum (or minimum) output of the multiplier is ned when

$$|x| = |y| = \tfrac{1}{2}l \tag{9}$$

s

$$|z|_{max} = |al^2| \tag{10}$$

is obvious from the above derivation that it is not neces- to have a symmetric parabolic characteristic [as might to be implied by (1)] in order to perform multiplication our quadrants. Indeed any portion of a quadratic acteristic will suffice; in practice it is more convenient to n a characteristic which is monotonic than one which bits a maximum (or minimum). The use of such an metric monotonic characteristic has been criticized(4) on rounds that the product term then appears as the difference ry much larger terms and is consequently less accurate. this is seldom a serious objection may be seen by ating F, the ratio of fractional noise level in the output n "asymmetric multiplier" to the corresponding noise in a "symmetric multiplier." This turns out to be

$$F = C\frac{\gamma + 1}{\gamma - 1} \tag{11}$$

e γ is the gain-ratio of the asymmetric non-linear units, he ratio of the maximum slope of the characteristic to the mum slope. The derivation of this formula is sketched ppendix A where it is shown that the constant C generally between 2·0 and 3·5. In practice it is not difficult to eve values of the gain-ratio γ, between 5 and 10,(2) which to values of F of less than 5. A three- or fourfold ease in noise-level is seldom unacceptable and in most tical cases the resultant noise-errors will still be smaller the errors due to imperfections of the characteristics. ce, in the interests of simplicity, it is generally preferable se non-linear units with monotonic characteristics.

3. TRUNCATION ERRORS

the curved quadratic characteristics of the non-linear s are synthesized from straight-line segments then the cipal source of error in the multiplier output will be the cation error due to the approximation of a curve by ight lines. (Other possible sources of error such as alignment, phase shift, etc., will not be considered here.) he parabola $W = aw^2$ is approximated in the interval $- \frac{1}{2}h$ to $w_0 + \frac{1}{2}h$ by a straight line then the "optimum" e of the line is equal to the slope of the parabola at w_0. criterion used is that of least mean square deviation which shows that at $w = w_0$ the line should lie at a distance /12 above the parabola. The resulting root-mean-square r of approximation is

$$\Delta W_{RMS} = ah^2/2\sqrt{45} = 0{\cdot}0746ah^2 \tag{12}$$

lst the maximum error is

$$\Delta W_{max} = ah^2/6 = 0{\cdot}1667ah^2 \tag{13}$$

s important to note that the errors are proportional to the are of the segment length (projected on the x-axis) and independent of w_0, i.e. the same accuracy can be achieved in approximating any portion of a quadratic characteristic with a straight segment of given length. Consequently all the considerations that follow hold equally for "symmetric" and "asymmetric" multipliers.

If the complete characteristics of the non-linear units are approximated by a series of N *equal* segments ($h = 2l/N$) then the resulting truncation errors in the multiplier output may be deduced by combining (12) and (13) with the appropriate equations of the previous section. This leads to the following formulae for the output error expressed as a fraction of the maximum output.

$$\delta_{RMS} = \sqrt{(8/45)}N^{-2} = 0{\cdot}38/N^2 \tag{14}$$

$$\delta_{max} = 1/N^2 \tag{15}$$

In practice ($N - 1$) diodes are sufficient to generate N segments and the experimentally observed truncation errors may be systematically smaller than those predicted by (14) and (15) because of the curvature of real diode-characteristics [see ref. (2)]. The form of dependence on N (or h), however, is not appreciably altered.

Apart from considerations of convenience and simplicity there are no *a priori* reasons why a set of *equal* segments should be used to approximate a quadratic characteristic. It might be possible to obtain smaller values of δ_{RMS}, the root-mean square error, if some of the straight segments were made shorter than others. The problem of selecting such an optimum distribution of segment lengths is considered in the next section.

4. OPTIMUM DISTRIBUTIONS OF SEGMENT LENGTHS

Suppose that the characteristics of the two non-linear units are to be approximated in the range (of inputs) $-l$ to $+l$ by N_1 and N_2 linear segments respectively. The aim is to find $h_1(r)$ and $h_2(s)$ the optimum distribution of segment lengths; $h_1(r)$ and $h_2(s)$ are the lengths of the rth and sth segments (projected on the input-axes) in the first and second non-linear units respectively.

It is, of course, necessary to adopt an optimizing criterion. A realistic and convenient one is furnished by the method of minimizing the weighted mean square error in the multiplier output. (Other criteria are possible but more difficult to handle analytically, although usually the final results will not differ much.) Accordingly we attempt to find $h_1(r)$ and $h_2(s)$ so that

$$\overline{E^2} = \iint \rho^2(x, y)[e_1(x + y) - e_2(x - y)]^2 dxdy \Big/ \iint \rho^2(x, y)dxdy \tag{16}$$

is a minimum. The integration in (16) is to be performed over the valid region of the (x, y)-plane specified by (6). The function $\rho(x, y)$ is a weighting factor whose choice depends on the statistics of the inputs x and y and on the relative importance of the errors in different parts of the (x, y)-plane. Thus if positive values of y occur more often than negative values $\rho(x, y)$ will be greater in the upper half of the plane than in the lower half. Similarly, if the output errors are to be small when the product xy is itself small then $\rho(x, y)$ will be large near the origin. In short, the choice of $\rho(x, y)$ is determined by the intended applications of the multiplier.

The mathematical details of the minimization of expression (16) for the mean square error are given in the Appendix. The results may be expressed in the form

$$h_1(r) = H_1(u) = \frac{h_{01}\int_{-\frac{1}{2}}^{\frac{1}{2}}[P_1(u)]^{1/5}du}{[P_1(u)]^{1/5}} \qquad (17)$$

where $$P_1(u) = \int_{-\frac{1}{2}}^{\frac{1}{2}}\rho^2[l(u+v),\, l(u-v)]dv \qquad (18)$$

and where $h_{01} = 2l/N_1$ is the length of a segment in a uniform distribution for which all the segments are equal in length.

The auxiliary variable u may be eliminated by using the relation

$$\frac{r-\frac{1}{2}}{N_1} = \frac{\int_{-\frac{1}{2}}^{u}[P_1(u)]^{1/5}du}{\int_{-\frac{1}{2}}^{\frac{1}{2}}[P_1(u)]^{1/5}du} \qquad (19)$$

thereby expressing the right-hand side of (17) in terms of r. Corresponding results hold for the distribution $h_2(s)$ in terms of v and of $P_2(v)$ which is defined as

$$P_2(v) = \int_{-\frac{1}{2}}^{\frac{1}{2}}\rho^2[l(u+v),\, l(u-v)]du \qquad (20)$$

The factor of improvement afforded by using the optimum distribution (17) in place of the uniform distribution $h_1(r) = h_{01}$ (and correspondingly in the second non-linear unit) may be defined as $I = \overline{E_0^2}/\overline{E^2}$, where $\overline{E_0^2}$ is the mean square error incurred if the uniform distributions are used. It follows from the Appendix that

$$I = \frac{h_{01}^4\int_{-\frac{1}{2}}^{\frac{1}{2}}P_1(u)du + h_{02}^4\int_{-\frac{1}{2}}^{\frac{1}{2}}P_2(v)dv}{h_{01}^4\left\{\int_{-\frac{1}{2}}^{\frac{1}{2}}[P_1(u)]^{1/5}du]\right\}^5 + h_{02}^4\left\{\int_{-\frac{1}{2}}^{\frac{1}{2}}[P_2(v)]^{1/5}dv\right\}^5} \qquad (21)$$

5. APPLICATIONS TO PARTICULAR CASES

To display the nature of the formal solution of the problem we consider a number of concrete examples each characterized by a particular choice of the weighting factor $\rho(x, y)$.

(*a*) $\rho(x, y) = \text{constant}.$

This is the appropriate weighting when the *absolute* error is to be minimized and when all combinations of inputs in the valid region (6) are equally probable. The optimum distributions are the uniform distributions:

$$h_1(r) = h_{01} \quad h_2(s) = h_{02} \qquad (22)$$

(*b*) $\rho(x, y) = \text{constant if } |x| \leqslant \tfrac{1}{2}l \text{ and } |y| \leqslant \tfrac{1}{2}l$

$\qquad = 0 \qquad \text{if } |x| > \tfrac{1}{2}l \text{ or } |y| > \tfrac{1}{2}l$

Because of the "diamond" shape of the valid region (see Fig. 1) large values of one input need not overload the multiplier if the other input is small. In a practical multiplier, however, it may be desirable to ensure that the input voltages are always less than $\frac{1}{2}l$ so that there is no possible danger of overload. In this case the above weighting factor is appropriate and the optimum distribution for both non-linear units is

$$h = \tfrac{5}{6}h_0(1-2|\mu|)^{-1/6} \qquad (23)$$

where $$\mu = \frac{r-\frac{1}{2}}{N_1} - \tfrac{1}{2} \quad \text{or} \quad \frac{s-\frac{1}{2}}{N_2} - \tfrac{1}{2} \qquad (24)$$

The plot of this distribution [marked (*b*) in Fig. 2] show that it does not differ greatly from the uniform distributio [marked (*a*)]. Indeed the improvement factor, I, is only 1·2

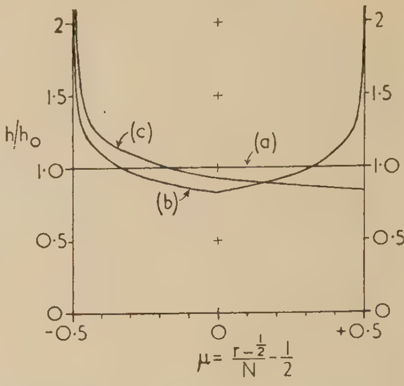

Fig. 2. Optimum distributions of segment lengths in cases (*b*) and (*c*) compared with the uniform distribution (*a*)

corresponding to a saving of 6% over the number of segmen needed if a uniform distribution had been used (since varies as N^{-4}).

(*c*) $\rho(x, y) = p^{1/2} \quad x > 0$

$\qquad = 1 \qquad x \leqslant 0$

If the input x is more often positive than negative (but input y uniformly distributed) then a weighting factor of t type is required. The optimum distribution is

$$h = \tfrac{5}{6}h_0\frac{p^{6/5}-1}{p-1}[(\mu+\tfrac{1}{2})(p^{6/5}-1)+1]^{-1/6} \qquad (25$$

The limiting distribution for large p, corresponding to never becoming negative, is plotted in Fig. 2 [curve (*c* the value of the improvement factor is 1·24 in this case als

(*d*) $\rho(x, y) = (x^2+y^2)^{-1/2}$

This choice of weighting effectively minimizes the outpu error when expressed as a fraction of the larger *input*; grea weight is given to errors made when both inputs are small

The optimum distribution is approximately

$$h = \tfrac{5}{4}h_0(2|\mu|)^{1/4} \qquad (26$$

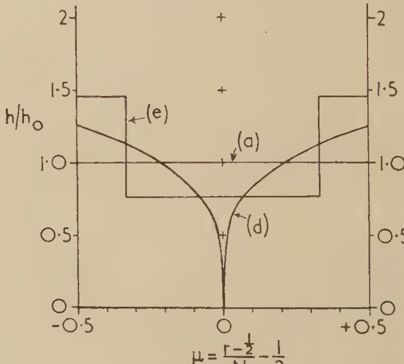

Fig. 3. Optimum distributions of segment lengths in cases (*d*) and (*e*) compared with the uniform distribution (*a*)

he plot of this distribution in Fig. 3 [curve (*d*)] shows that ıly differs appreciably from the uniform distribution in a ll central region. The improvement factor cannot be uated directly in this case,* but the expression $I \sim 0{\cdot}4$ $+ \log_e 2N)$ may be derived. Thus with ten segments mprovement factor of 1·6 is obtainable.

$$\rho(x, y) = q \text{ if } |x - y| \leqslant \alpha l$$
$$= 1 \text{ otherwise.}$$

his weighting factor is appropriate if the inputs x and y so correlated that their difference is usually less than αl. optimum distribution for the second non-linear unit is

$$\left.\begin{aligned} h_2 &= h_{02}[\alpha + (1 - \alpha)q^{-2/5}] \quad \text{for } \mu < \mu_0 \\ &= h_{02}[\alpha q^{2/5} + (1 - \alpha)] \quad \text{for } \mu \geqslant \mu_0 \end{aligned}\right\} \qquad (27)$$

ere $\mu_0 = \frac{1}{2}[1 + (1 - \alpha)/\alpha p^{2/5}]^{-1}$

uniform distribution optimizes the first non-linear unit, a greater number of segments are required if the accuracy he second unit is to be matched. The curve (*e*) in Fig. 3 he plot of the distribution for h_2 when $q = 5$ and $\alpha = \frac{1}{2}$. his case the improvement ratio is 1·9 (assuming matching) ch corresponds to roughly an 18% saving of segments in second non-linear unit.

$$\rho(x, y) = \frac{1}{z} = \frac{1}{xy}$$

This is the weighting factor that must be used in order to ıimize the *fractional* error in the output. It is not, howr, possible to find an optimum distribution for this case ce the required integrals diverge. This is an illustration of characteristic fact that a practical quarter-squares multier will exhibit finite errors even when one input is identically o.

6. CONCLUSIONS

t has been shown (in Section 2) that in most practical es a monotonic asymmetric characteristic is to be preferred the non-linear units in a quarter-squares multiplier. ovisos are that a large gain ratio γ can be realized and ıt the slight increase in noise level over the symmetric angement is not objectionable.

Formulae have been given (in Section 3) for the truncation ors in a multiplier with N equal segments approximating ch non-linear characteristic. On the basis of a least-squares terion expressions for the optimum distributions of unequal gment lengths can be obtained (Section 4) in terms of a ighting factor $\rho(x, y)$ determined by the proposed applicaıns of the multiplier. Evaluation of these theoretical rmulae for a number of specific examples shows that, except extreme cases, the optimum distributions are close to the iform distribution with equal segments. The improvements tainable are equivalent to a reduction of between 5 and 20% the number of segments needed to achieve a given accuracy. ıis means that practical considerations of convenience ould normally lead to the use of the uniform distribution, e consequent loss of accuracy being not very great. It is ıportant, however, to note the converse conclusion, namely, at any distribution differing appreciably from the uniform distribution will nearly always lead to a large increase in the mean square error. As an example suppose that the segment lengths projected on the *output*-axis of a non-linear unit, are made equal (this is a convenient arrangement in some designs of diode switching networks). The use of this distribution in circumstances where the uniform distribution would be appropriate leads to an increase in the root-mean-square error of $\frac{1}{4}(\gamma + 1)^2$. Thus with a typical gain ratio of $\gamma = 5$ the accuracy of the multiplier is reduced by a factor of nine.

APPENDIX A

Suppose that the root-mean-square noise amplitude at the output terminal of a non-linear unit is σ (expressed as a fraction of the maximum output amplitude). In the case of a "symmetric multiplier" $b = c = 0$ in equation (2) of Section 2, so that

$$|W|_{max} = |a|l^2 \qquad (A.1)$$

The noise waveforms from the two non-linear units combine to give a noise level in the multiplier output of

$$\frac{[(al^2\sigma)^2 + (al^2\sigma)^2]^{1/2}}{|z|_{max}} = \sqrt{2}\sigma \qquad (A.2)$$

[using equation (10)].

The non-linear characteristics of an "asymmetric multiplier" of gain-ratio γ may be determined from the definition of γ which gives

$$|b| = 2|a|l\frac{\gamma + 1}{\gamma - 1} \qquad (A.3)$$

so that by equation (2)

$$|W|_{max} = \tfrac{1}{2}|f(l) - f(-l)| = |b|l = 2|a|l^2\frac{\gamma + 1}{\gamma - 1} \qquad (A.4)$$

Equation (4) of Section 2 shows that in this case a third source of noise in the multiplier output arises from the nonvanishing term $2by$. Assuming that the noise level at the y-input terminal is ρ, the output noise level of an "asymmetric multiplier" is

$$\frac{[(bl\sigma)^2 + (bl\sigma)^2 + (2bl\rho)^2]^{1/2}}{|z|_{max}} = 2\frac{\gamma + 1}{\gamma - 1}\sigma\left[2 + 4\left(\frac{\rho}{\sigma}\right)^2\right]^{1/2} \qquad (A.5)$$

Thus the ratio of noise levels in the two cases is

$$F = 2\left[1 + 2\left(\frac{\rho}{\sigma}\right)^2\right]^{1/2}\frac{\gamma + 1}{\gamma - 1} = C\frac{\gamma + 1}{\gamma - 1} \qquad (A.6)$$

It may be safely assumed that $\rho \leqslant \sigma$ since the noise level in the output of a non-linear unit will depend on the noise levels of both the x- and y-inputs, as well as on internal noise sources. It follows that C lies between 2·0 and 3·5.

This derivation must be modified if the various noise waveforms are correlated. Thus for systematic drift or hum the appropriate value of C may be somewhat larger (or smaller), depending on the circuit details, etc.

APPENDIX B

The aim of this Appendix is to find distributions $h_1(r)$ and $h_2(s)$ which minimize the expression

$$\overline{E^2} = \iint \rho^2(x, y)[e_1(x + y) - e_2(x - y)]^2 dxdy \Big/ \iint \rho^2(x, y)dxdy \qquad (B.1)$$

---

* The integrals in the numerator of (21) diverge logarithmically. ıis is an indirect consequent of the smoothing approximation ade in Appendix B. By cutting off the integrals or modifying x, y) at the origin, finite results can be obtained.

subject to the conditions

$$\sum_{r=1}^{N_1} h_1(r) = \sum_{s=1}^{N_2} h_2(s) = 2l \qquad \text{(B.2)}$$

On introducing the auxiliary variables u and v, proportional to the inputs to the non-linear units, by

$$x + y = 2lu \qquad x - y = 2lv \qquad \text{(B.3)}$$

(see Fig. 1) the expression (B.1) may be rewritten as

$$\overline{E^2} = \int_{-\frac{1}{2}}^{\frac{1}{2}}\int_{-\frac{1}{2}}^{\frac{1}{2}} P(u, v)[e_1^2(2lu) + e_2^2(2lv) - 2e_1(2lu)e_2(2lv)]dudv/P_0 \qquad \text{(B.4)}$$

$$\text{where} \quad P(u, v) = \rho^2(x, y) = \rho^2[l(u + v), \quad l(u - v)] \qquad \text{(B.5)}$$

$$\text{and} \quad P_0 = \int_{-\frac{1}{2}}^{\frac{1}{2}}\int_{-\frac{1}{2}}^{\frac{1}{2}} P(u, v)dudv \qquad \text{(B.6)}$$

We may assume that the mean errors $\overline{e_1(2lu)}$ and $\overline{e_2(2lv)}$ vanish (or, at least, are negligibly small) since otherwise the approximation would be unreasonably bad. It was observed in Section 3 that the root-mean-square errors in the region of a given segment are proportional to h^2. This means that the squared terms of the integrand of (B.4) may be written as

$$e_1^2 = k[h_1(r)]^4 \quad \text{and} \quad e_2^2 = k[h_2(s)]^4 \qquad \text{(B.7)}$$

where, by equation (12), the constant k may be assigned the value 1/180. This "smoothing" approximation will be valid provided $P(u, v)$ does not vary very rapidly over the distance of a single segment and provided the lengths of adjacent segments do not differ too drastically.

To proceed further it is helpful to regard r and s as continuous variables and write

$$h_1(r) = H_1(u) \qquad h_2(s) = H_2(v) \qquad \text{(B.8)}$$

This is permissible since u and v represent the inputs to the non-linear units, and so determine r and s uniquely once the distributions $h_1(r)$ and $h_2(s)$ are fixed. We then have the relations

$$2l\frac{du}{dr} = h_1(r) = H_1(u) \qquad 2l\frac{dv}{ds} = h_2(s) = H_2(v) \qquad \text{(B.9)}$$

from which it follows that

$$r - \tfrac{1}{2} = \int_{-\frac{1}{2}}^{u} \frac{2ldu}{H_1(u)} \qquad s - \tfrac{1}{2} = \int_{-\frac{1}{2}}^{v} \frac{2ldv}{H_2(v)} \qquad \text{(B.10)}$$

[The fraction $\frac{1}{2}$ is included because as u runs from $-\frac{1}{2}$ to $+\frac{1}{2}$ r (regarded continuously) runs from $\frac{1}{2}$ to $(N_1 + \frac{1}{2})$].

The conditions (B.2) may now be expressed as

$$\int_{-\frac{1}{2}}^{\frac{1}{2}} \frac{du}{H_1(u)} = \frac{N_1}{2l} = \frac{1}{h_{01}} \qquad \int_{-\frac{1}{2}}^{\frac{1}{2}} \frac{dv}{H_2(v)} = \frac{N_2}{2l} = \frac{1}{h_{02}} \qquad \text{(B.11)}$$

and [using (B.7)] (B.4) becomes

$$\overline{E^2} = (k/P_0)\left\{\int_{-\frac{1}{2}}^{\frac{1}{2}} P_1(u)[H_1(u)]^4du + \int_{-\frac{1}{2}}^{\frac{1}{2}} P_2(v)[H_2(v)]^4dv\right\} \qquad \text{(B.12)}$$

$$\text{where} \quad P_1(u) = \int_{-\frac{1}{2}}^{\frac{1}{2}} P(u, v)dv \qquad P_2(v) = \int_{-\frac{1}{2}}^{\frac{1}{2}} P(u, v)du \qquad \text{(B.13)}$$

The minimization of (B.12) may now be accomplished in the normal way by setting $\delta\overline{E^2}$ equal to zero and taking account of the conditions (B.11) by means of Lagrange multipliers. This leads to

$$H_1(u) = \lambda_1[P_1(u)]^{-1/5} \qquad H_2(v) = \lambda_2[P_2(v)]^{-1/5} \qquad \text{(B.14)}$$

The multipliers λ_1 and λ_2 may be determined by substitution in (B.11) and hence the explicit expression (17) of Section 4 is derived for $H_1(u)$ [and the corresponding expression for $H_2(v)$]. Substitution of these results into (B.10) yields the explicit relations between r and u [equation (19) of Section 4] and between s and v.

This completes the solution since, by eliminating u and v, the optimum distributions $h_1(r)$ and $h_2(s)$ can be calculated in the required terms. The improvement factor $I = \overline{E_0^2}/\overline{E^2}$ may be derived from (B.12) by substituting the optimum expressions for $H_1(u)$ and $H_2(v)$ and by substituting the corresponding values for uniform distributions, namely,

$$H_1(u) = 2l/N_1 = h_{01} \qquad H_2(v) = 2l/N_2 = h_{02} \qquad \text{(B.15)}$$

This procedure leads directly to equation (21) of Section 4.

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Two portable thermistor radiometers

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The construction and calibration of two portable radiometers, suitable for micrometeorological studies, is described. One instrument measures the hemispherical short-wave radiation and the other measures directly the total radiative flux through a plane. Attachments to the latter instrument permit total hemispherical radiation and psychometric measurements to be made. Small dry batteries, a tiny motor, a simple Wheatstone's bridge and thermistors are used.

INTRODUCTION

two occasions, first in 1950 and secondly in 1953, Svenn ig and the writer had the opportunity of landing from a ll aircraft on unknown ice caps in Baffin Island, Canada, order to spend the summer assessing their glacial- eorological regimes.(1) The nature of those enterprises anded that our instruments should be as light, simple and ust as possible. In 1950 the only radiation instrument could be obtained was a Campbell–Stokes sunshine rder and consequently our study of the heat exchange at ice surface(2) had to depend for radiation balance on irical correlations. This was rather unsatisfactory and the second occasion the writer constructed two radio- ers. Several requests received for details of these simple ruments, some from glaciologists and some from people lying industrial micrometeorology, have shown a general l for portable instruments of this type and justify an ount of their construction and calibration.

hermistors were used as the temperature-sensitive elements oth instruments on account of the simplicity and lightness he Wheatstone's bridge required for measurement and ause the same bridge and other thermistors were to be i for englacial and air temperature measurements.(3) It the thermistor that made the instruments portable.

he first instrument measures the hemispherical short-wave ation and is similar to the Moll–Gorczynski solarimeter(4); second instrument measures basically the net flux of total ation through a plane and is similar to other total radia- fluxmeters of the blown type.(5,6,7)

HE HEMISPHERICAL SHORT-WAVE RADIOMETER

) *Construction.* Details of the construction of this rument are given in Fig. 1. Its overall dimensions, with lid on, are 3½ in. (9 cm) × 2½ in. (6 cm) diameter, and it ghs 4 oz (110 grm). The description of its construction ts at the centre and proceeds outwards. Two ther- tors (T_b and T_w) (Standard Telephones and Cables type 250/300) are mounted on mica bridges A_1 and A_2 respec- ly. A_2 forms the support of the lower circular screening B of a pentode radio valve (actually a Telefunken type 100). Bridge A_1 is supported just below the lip of the *B*. The upper surface of the copper disc (5/32 in., 4 mm neter) of thermistor T_b is painted black and receives the ct radiation; it lies at the centre of the glass dome *D* and at the centre of a screening disk *E* of thin aluminium. rmistor T_w is painted white all over and is screened from ct radiation by two or more white screens in every direc- . Hence its temperature approximates to the ambient air perature. The thermistor leads are connected to con- ient valve pins and a wire-wound matching resistor *F* is ed. A cylindrical screen of thin tin-plate *G*, perforated with a few holes towards its lower end, is mounted on the valve base *C*.

The whole inner unit, as described so far, is set axially into a small tin-plate can *H*. The lid of the can is fixed to the valve base and the can proper surrounds the screen *G*. The edge of the glass dome is cemented into a ring of copper foil of U-shaped section, which is soldered on to the bottom of the can. When the instrument is completed, the glass dome together with the can may be pulled upwards away from its lid and the inner unit. This enables a packet of silica gel, kept in the space between *H* and *G*, to be changed. All inner surfaces are painted with matt white paint and the outside is painted with white gloss paint. Another small tin-plate can *J*, painted matt black inside and gloss white outside, is

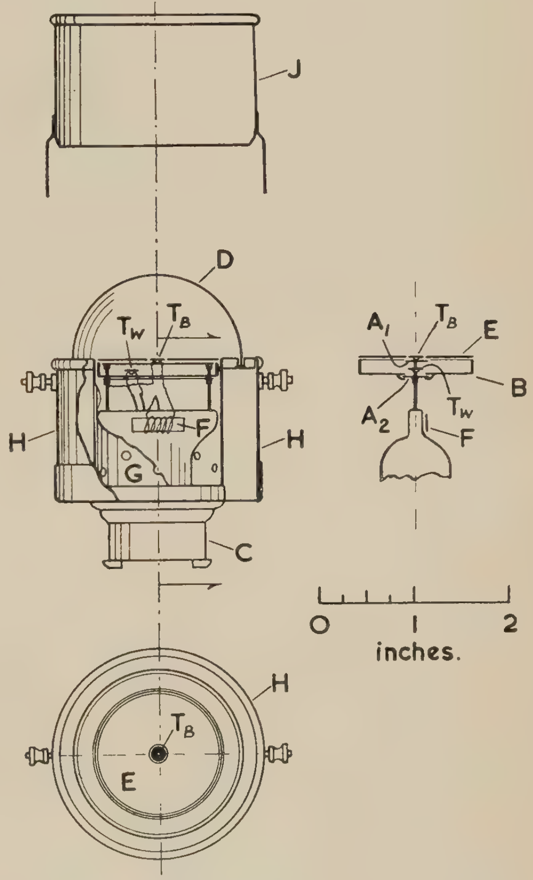

Fig. 1. Constructional details of the hemispherical short-wave radiometer

used to form a protective cover for the glass dome and for recording the zero of the instrument.

The hemispherical glass dome is about 0·2 mm thick and is the bottom half of a round-bottomed flask of Saxony glass. It was cracked off along a diamond scratch with an electrically-heated wire ring.

(*b*) *Calibration.* The Wheatstone's bridge circuit used for measuring the radiation, i.e. the difference in temperature of the two thermistors, will be mentioned later, but it will suffice for the moment to note that the same bridge, suitably adjusted, was used for both instruments. It was a modification of one used earlier for simple temperature measurements.(3) One thermistor formed one arm of the bridge, and the other, connected in series with the matching resistor *F*, formed the adjacent arm.

Measurements were made of the resistance of the two thermistors in air at a few selected temperatures. Then the value of *F* was calculated so that, when both thermistors were at the same temperature, the ratio of the resistance of one to the resistance of the other, plus the resistance *F*, remained almost constant at all temperatures likely to be encountered in the radiometer.

The radiometer connected to the bridge was calibrated at Kew Observatory by comparison with a substandard Moll–Gorczynski solarimeter. Each instrument was subjected to radiation at normal incidence from a 2000 W tungsten filament lamp. A standardized procedure was followed and the radiation was varied by altering the lamp distance and its voltage. The cosine law response was checked. The calibration curve of radiation against bridge potentiometer dial reading is given in Fig. 2. The relation is practically linear; 1 cal/cm^2/min corresponds to about 130 dial divisions, which represents an increase in the ratio of the thermistor resistances of about 1·23 times.

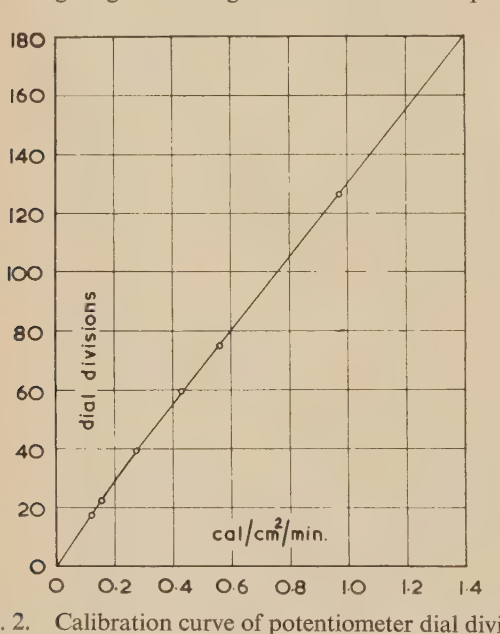

Fig. 2. Calibration curve of potentiometer dial divisions against hemispherical short-wave radiation

(*c*) *Performance.* The performance of this instrument in the Arctic was entirely satisfactory. The zero of the instrument did not vary according to the bridge reading by more than ±2 dial divisions (i.e. about ±0·015 cal/cm^2/min) at air temperatures varying from about −19 to +0·5° C. Almost the whole of this variation could be accounted for by slight temperature effects in the fixed arms of the bridge and by a slight lack of matching of the thermistor resistance temperature characteristics. Hence the thermistors remained adequately stable and the zero of the instrument is still the same after 3 years.

The maximum incoming solar radiation recorded on the unobstructed horizontal plane of the ice cap at 2050 m altitude at local noon in 66° 59′ N. was about 1·4 cal/cm^2/min (i.e. beyond the range of calibration). This occurred during a lull in the worst blizzard we encountered. The snow was still blowing with the wind at 15 miles/h and the air temperature was about −16° C; clear blue sky was just visible overhead and it felt quite warm.

The formation of hoar frost on the outside of the glass dome was troublesome, but on account of the thinness of the glass it was very easily removed by the warmth of the hand. Where sufficient power is available a small electric heater inside the instrument would serve to avoid hoar frost and the use of a drying agent.

THE TOTAL RADIATION FLUXMETER

(*a*) *Construction.* This instrument gives directly the radiation balance required to assess the heat exchange at the surface of a body such as the ground or a glacier. It could be used for a similar purpose in many industrial heat exchange problems, and it is particularly suitable for studies where readings may be required in several positions at frequent intervals. The writer was introduced to this type of instrument by Mr. J. MacDowall of the Meteorological Office, and the present design is similar to his early model(7) except that it is smaller, uses thermistors and a blower small enough to operate on dry batteries. This instrument, like the previous one, was constructed mainly from odds and ends in a home workshop.

The construction of the instrument is detailed in Fig. 3. The basic unit, labelled *A*, is a blower which directs a constant blast of air over a blackened heat meter plate. The overall dimensions of this unit is 14 in. (35 cm) × 3 in. (8 cm) × $3\frac{1}{2}$ in. (9 cm) and it weighs 11 oz (320 gm). The accessories shown in Fig. 3 are the following:

B, a Perspex cover for protecting the heat meter plate,
C, an insulated black box for recording the instrument zero,
D, a black body radiator for providing a measurable source of radiation on one side of the heat meter plate,
E, an aspirated psychrometer which makes use of the suction side of the blower.

The construction of the basic unit *A* is now described. The fan motor *a* is a permanent magnet d.c. motor of war-time German origin, rated at 1·5 W and 24 V for 10 minutes running. It was operated at 18 V (4 × 4·5 V small bell batteries) for long periods. The motor is well made with ball bearings and carbon brushes, and is ideal for the job; the maker is unknown. The fan rotor *b* of centrifugal type is $2\frac{1}{2}$ in. (6·5 cm) diameter × $\frac{5}{8}$ in. (1·5 cm) wide and was built up from pieces of Perspex 1/16 in. (1·6 mm) cemented together. The fan housing *c* is a tin-plate box. The divergent fan duct *d* is two pieces of tin-plate bent up and soldered together. The duct outlet is 2 in. (5 cm) × $\frac{3}{8}$ in. (0·95 cm) in cross-section. The wind speed 1 in. (2·5 cm) in front of the outlet is about 15 miles/h with the heat meter plate removed. The whole blower unit is painted white.

The heat meter plate *e* is a rectangular sheet of polystyrene 1 mm thick, effective width 2 in. (5 cm) and $1\frac{1}{8}$ in. (2·9 cm) ng; the upstream and downstream edges are bevelled. ass-beaded thermistors t_t, t_b, separated from the copper scs of Standard Telephones and Cables thermistors type .3250/300, are set in recesses and grooves carved on either le of the polystyrene sheet. The thermistors are set slightly f centre to avoid interference of one with the other. The ttened faces of the glass beads are aligned with the poly-/rene surface and the platinum leads are insulated with ellac. A piece of copper foil (0·005 in. or 0·013 cm thick) cemented in a press over each surface of the polystyrene d this whole sandwich forming the heat meter plate is ainted black. The heat meter plate is accurately aligned n the centre of the duct outlet and it is supported from either ide of the duct by four tin-plate angles clipped together in airs. The upstanding edges of these angles serve also to onfine the air flow over the heat meter plate, and to deflect ross winds.

The leads from the motor and the thermistors are brought o the terminal board *f* mounted on one side of the duct. The thermistor matching resistor is attached to this board.

The black box *B* provides an equal source of radiation on ither side of the heat meter plate with the blower in action. t is a rectangular tin-plate box lagged internally with fibre oard; a light-trap louvre *g* allows the air to escape at one nd and the box closes around the duct at the inlet end. Fittings support it from the duct. The position of the heat neter plate inside the box is shown in three of the diagrams n Fig. 3.

The black body radiator *D* is a sheet of aluminium 1/16 in. (1·6 mm) thick, bent down along three edges to screen lateral radiation, which can be bolted on the top side of the duct about ¼ in. (6·4 mm) clear of the heat meter plate. The upper side of the aluminium is highly polished and the underside is blackened. A thermistor t_a, type M.3250/300, is set flush with the blackened surface of the aluminium and arranged centrally over the heat meter plate. The thermistor leads are taken through to the topside of the aluminium to terminals *h*; these leads are covered over with bright aluminium foil. This device shields one side of the heat meter plate completely from direct external radiation and produces a source of radiation which is measured by the absolute temperature of thermistor t_a.

The aspirated psychrometer *E* uses two thermistors, t_w and t_d, Standard Telephones and Cables type F.2311/300, fitted with small brass pellets around the beads to reduce their response.(8) They are mounted in a valve base holder *j*, which is bolted to a tin-plate can *k*. The lower ends of the thermistors are screened with two small cylindrical pieces of tin-plate *l* supported on screen *m*. A double-walled tin-plate can *n*, divided axially inside, is supported from the can *k* and screens the upper ends of the thermistors. The instrument is painted white inside and out and fits over a ring on the fan inlet of unit A. The air paths through the psychrometer, over the heat meter plate and through the black box, are indicated in Fig. 3.

(*b*) *Calibration.* The fluxmeter was calibrated in the Kew Observatory radiation laboratory. The instrument was placed between two large glass plates and subjected to the

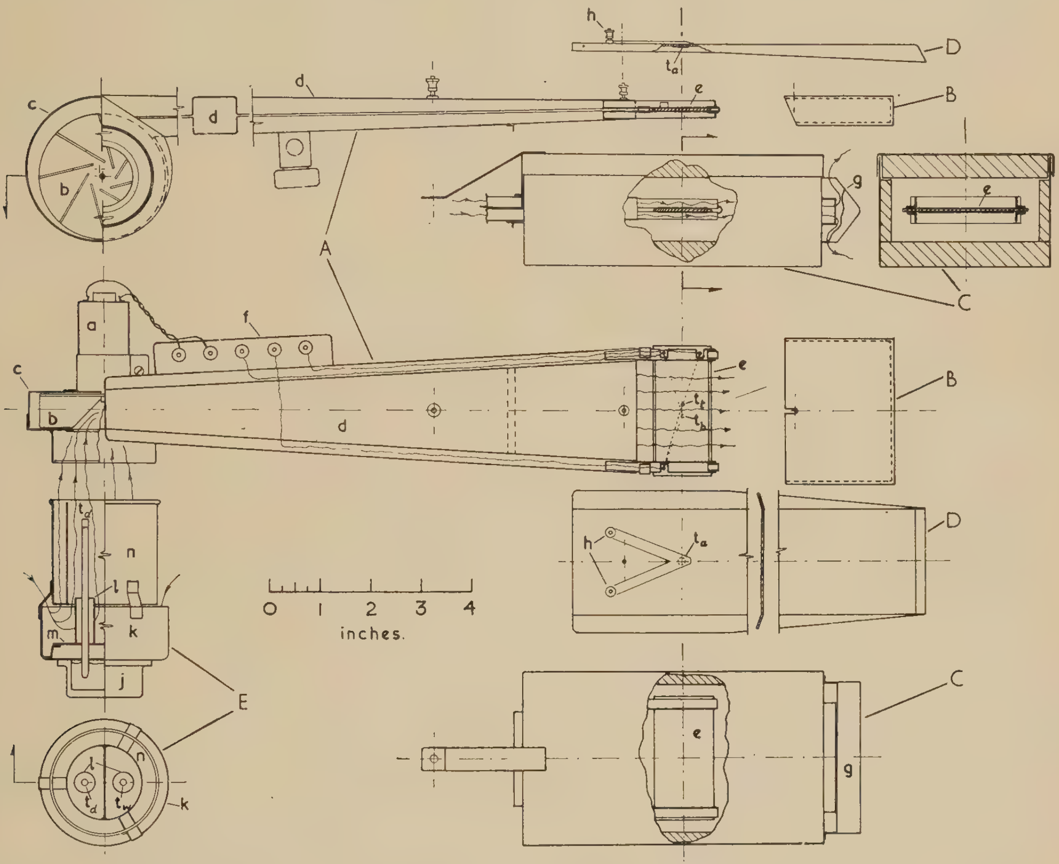

Fig. 3. Constructional details of the total radiation fluxmeter and its accessories

short-wave radiation from a 2000 W lamp. The radiation intensity was measured by a standardized Linke–Feussner actinometer set at the same distance from the lamp as the heat meter plate. The method is described in more detail by MacDowall.(7) Calibrations were made with both the topside and the underside (see Fig. 4) of the heat meter plate at normal incidence to the radiation.

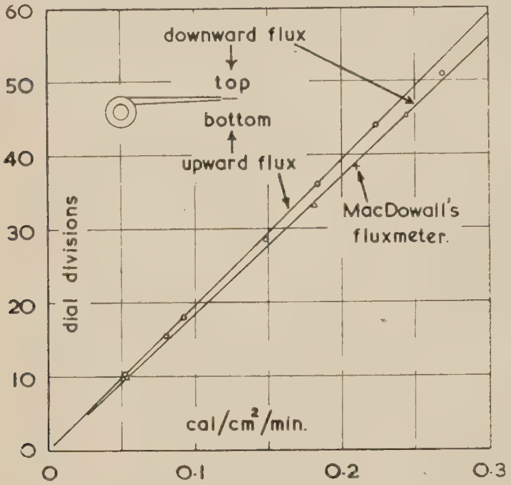

Fig. 4. Calibration curve of potentiometer dial divisions against total radiation flux

As a check on the above calibration, the instrument was also subjected to long- and short-wave radiation from the lamp and its housing (the glass plates were removed), and the radiation flux was measured by MacDowall's instrument using the mean sensitivity* of his instrument of 68 μV/mW/cm^2.

These calibrations are plotted in Fig. 4. The calibration seems to be linear, but there is a difference of about 6% between the sensitivity for net upward and downward fluxes, which could have been eliminated by adjusting the position of the flux plate in the air stream. The value obtained from MacDowall's instrument agrees well with the Linke–Feussner calibration. The sensitivity is 190 ± 6 potentiometer dial divisions per cal/cm^2/min, which corresponds to a change in the resistance ratio of the thermistors of about 1·07 times.

The temperature calibrations of the thermistors t_w and t_d in the psychrometer, and of t_a in the black body radiator were obtained in the usual way; the black body radiation of plate *D* was plotted directly against dial divisions for convenience.

(*c*) *Performance.* The performance of the radiation fluxmeter in the Arctic was quite satisfactory. The instrument zero was checked frequently by means of the black box *C* and it varied by ±6 dial divisions. No drift was noted in the thermistors and the variation could be accounted for by slight lack of matching between them, by small temperature effects in the fixed arms of the bridge and by the black box being not exactly at uniform temperature. After 3 years the thermistors show a small drift; the instrument zero having changed by about 10 dial divisions or a change in the thermistor resistance ratio of less than 0·4%.

The instrument was not used in winds greater than about 12 miles/h, since at that speed it would be enveloped in blowing snow and the fan became choked when stationary. As far as possible it was arranged to blow with the wind and so that the sensitive part of the flux plate received the direct solar radiation. A small circular bubble was used to level the flux plate.

No hoar frost ever formed on the flux plate even when it was severe on other parts of the instrument and on all other meteorological instruments. In thick wet fog, which was fairly frequent, the blower kept both sides of the flux plate equally wet and it is believed that the flux measurements under these conditions were reasonably correct.

At the site mentioned previously the maximum recorded total flux received by the ice cap amounted to 0·32 cal/cm^2/min at about local noon in the middle of July on one of the warmest days during thick fog; values nearly as large were recorded earlier in the month under clear skies. The maximum outgoing flux that was recorded amounted to 0·25 cal/cm^2/min and was recorded on several occasions about 6 hours after local noon when the sky was clear.

THE WHEATSTONE'S BRIDGE

The circuit diagram of the bridge is given in Fig. 5. The fixed resistors are of high stability radio type. The 200 Ω rotary potentiometer is wound in Eureka wire and is switched into the four positions 1, 2, 3, and 4 between a series of fixed resistors to form the variable arms. The galvanometer is a ±25 microammeter (2½ in. diameter) and the battery is two dry cells (3 V).

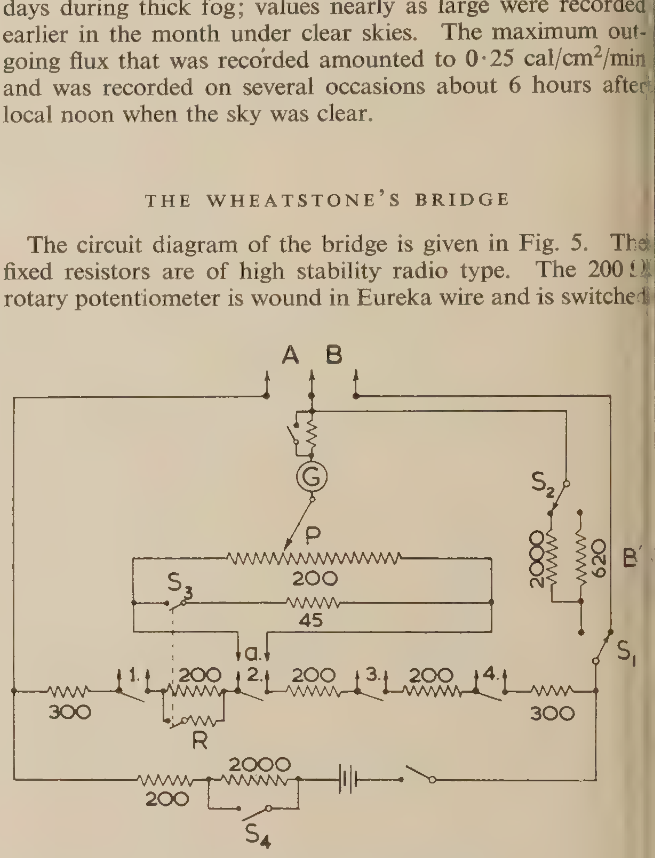

Fig. 5. Circuit diagram of Wheatstone's bridge used for temperature and radiation measurements. Resistances are in ohms

When measuring temperatures the thermistor is connected to arm *A*, switch S_3 is open, the battery series resistance is 2200 Ω, and the arm *B* is loaded, according to the type of thermistor, with either 620 or 2000 Ω by switches S_1 and S_2.

When the radiometers are used their thermistors are joined to form the arms *A* and *B* (switch S_1 open). For reading the hemispherical short-wave radiometer the remainder of the circuit is kept as described in the previous paragraph and all measurements could be made with the potentiometer in position 3. In order to read the fluxmeter the sensitivity has to be increased. The current is increased by reducing the battery resistance to 200 Ω and the potentiometer is shunted h a 45 Ω resistor by switch S_3. The other half of this tch also applies a shunt across one of the 200 Ω resistors bring the instrument zero flux reading to the centre of the entiometer dial. The extra heat dissipated by the ther- stors by this modification is of no consequence, since it is local difference in temperature across the flux plate which being measured and not absolute temperature. If the dge had been constructed in the first place primarily for asuring the flux meter plate the potentiometer arms would ve been arranged in a better way.

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* There appears to be an error in the units in Table 3 of MacDowall's paper. The sensitivity is quoted as V/mW/cm^2, but the correct units are μV/mW/cm^2.

ACKNOWLEDGEMENTS

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A bolometer detector for the measurement of shock velocity in low density gases

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In applying the shock tube as a device for the study of chemical kinetics it is necessary to measure the velocity of the shock wave so that the energy input is characterized by the shock strength. A suitable detector of a shock wave, used to determine shock velocities, should have adequate sensitivity in order to detect weak shocks in low density gases and also have a high speed of response to reduce timing errors to a minimum. It should also be robust and resistant to corrosive substances and be able to be placed in the shock tube so that the shock front is not disturbed in passing it. This note describes such a detector.

ecently(1) attention has been drawn to the use of shock aves as a means of initiating chemical reactions. The creases in translational and rotational energies of the ocked molecules are apparent as a uniform instantaneous ating of the gas. In order to characterize this energy input is necessary to know the strength of the shock or its Mach umber. A well-developed one-dimensional mathematical eory then allows of calculation of pressure, temperature and ensity changes across the transition.(2) The velocity of the ock is determined by measuring the time that it takes to ass between two or more fiducial points in the reaction tube. everal techniques have been developed to detect the shock ont, but none is of general application.

When the shock tube is applied to problems associated ith high speed flight(3) a Schlieren system is often used to llow the density change resulting from the passage of the ock front. This method becomes increasingly unreliable hen either the shock strength or the density of the shocked as is decreased. The velocity of detonations and strong ocks has been accurately measured by Knight and Duff(4) ho detected the conductivity of the ionized gas behind e shock front. However, when the temperature of this eated gas is below 1000° K the method becomes difficult apply.

A positive ion oscilloscope trigger for shocks in low density ases has been proposed by Venable.(5) Here a positive ion urrent exists across the shock tube perpendicular to its ngth. Interruption of the current by the shock front results in output signals depending upon the shock strength. This method is limited to shocks through gases and vapours which are not appreciably affected by a high voltage discharge. Also the position of the needle which collects the ions is likely to disturb the shock front as it passes. Dosanjh(6) has successfully used a very fine electrically heated wire to detect the change in its resistance due to the heated gas produced by the shock wave. This type of detector has a good frequency response, is applicable to shocks through low density gases and can be used with very weak shock waves. Its chief disadvantage arises from the extremely thin wire that has to be soldered between two electrodes.(7) These detectors are very frail and awkward to construct and their position in the tube may disturb the planarity of the shock front. In an investigation of the dissociation of dinitrogen tetroxide(8) multiplier phototubes were used to follow changes in light transmission caused by the shock wave producing the yellow coloured nitrogen dioxide molecules.

It became desirable in current investigations to develop a detector of a shock wave which could be used generally and not for a specific system. It would have to operate for non-ionizing gases whose densities may be extremely low and could not depend on colorimetric techniques. Such a detector should have adequate sensitivity for weak shock waves as well as a high frequency response in order to reduce timing errors. It should be robust and resistant to corrosive substances. It should also be able to be mounted in the shock tube so as not to disturb the shock front as it passed by.

THE BOLOMETER DETECTOR

The shock waves were generated in a shock tube consisting of a high pressure chamber (mild steel, 18 in. long, 1·0 in. internal diameter) separated by Cellophane diaphragms from a low pressure expansion channel (Pyrex, 54 in. long, 1·0 in. internal diameter). Hydrogen or helium was used as driver gas and air or polyatomic molecules such as ethanol used in the expansion channel. The strength of the shock wave is related to the pressure ratio across the diaphragm before it is shattered and to the ratio of the velocities of sound in both gases. The pressure, density and temperature changes across the shock front are abrupt. At low pressures the detection of both strong and weak shocks is difficult with a pressure pick-up due to mechanical vibration propagated along the shock tube walls. Because the change in refractive index is proportional to the change in density, Schlieren methods are not very sensitive with low density gases.

The temperature change across the shock front, on the other hand, is of the order of degrees centigrade even for weak shocks. It was therefore considered that this temperature variation could be detected with a resistor bolometer so that a significant pulse would be obtained after amplification. In principle the bolometer consisted of a non-conducting medium which held two electrodes approximately 1 mm apart and between whose ends was placed a thin film of metal. With the requirements listed above in mind, gold was chosen as the metal to form the film as it is non-corrodible and possesses a relatively high coefficient of resistivity. The thin film of gold was evaporated across the electrodes under vacuum using a standard technique.(9) The change in resistance of the bolometer as the gold was being plated was followed with an ohm-meter. It was generally found that the resistance of the detectors settled at a value which was slightly lower than that observed when the evaporating process was stopped.

Several materials were tested as non-conducting media to hold and separate the electrodes across which the gold junction was made. Electrodes of copper, gold, aluminium or tungsten were sealed into plugs made from Araldite *D* resin or from Perspex. When set, a section of the plug was cut to expose the two electrodes. The end of the section was ground smooth with alumina paste. Each combination produced unstable and not very robust detectors. Under a microscope a small crack was invariably seen about the circumference of the electrode, due apparently to non-wetting of the metal surface by the plastic. When a gold film was evaporated between the electrodes the crack had to be bridged and this caused instability. Tungsten electrodes sealed into a glass plug were eventually found to be best for holding the gold film. To make certain of preventing a contact resistance between the gold and the tungsten a thick layer of gold was evaporated over the whole end section of the plug except for a narrow strip between the electrodes screened by a thin wire mask. The final resistor was then plated as a bridge across these two large gold-plated sectors. The final form of the plug, its method of formation and manner of mounting in the cylindrical Pyrex expansion channel is illustrated in Figs. 1(*a*) and 1(*b*).

Detectors of 10 to 20 Ω resistance were found to be satisfactory. Higher values gave detectors which were both noisy and prone to failure. The lower resistance detectors have carried a current of 0·5 A without damage but normally operate at 30 mA. Unless struck a direct end-on blow the bolometers have proved extremely sturdy and capable of experiencing many hundred shocks even when exposed to the reflected shock where the heating effect of the shocked gas i doubled in intensity.

The smoothing of the end of the detector plug by grinding with alumina paste is only to ensure that neither the tungsten nor the glass stand proud of the other. Under a microscope complete wetting between metal and glass was seen to have taken place, so that a strong metal film from electrode to electrode along the surface of the glass resulted. The shaft of the plug was ground to fit snugly into the hole in the expansion channel so as to be flush with the inside wall. The seal was made vacuum-tight by a liberal coating of Picein wax [Fig. 1(*b*)].

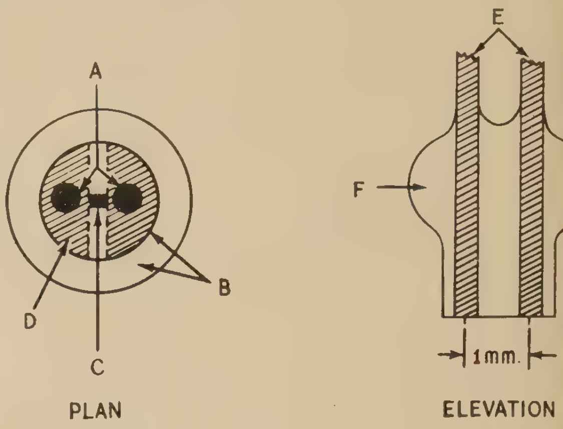


Fig. 1(*a*). Design features of gold bolometer

A, *E*, tungsten electrodes; *B*, *F*, glass plug; *C*, resistor bridge; *D*, heavy gold film.

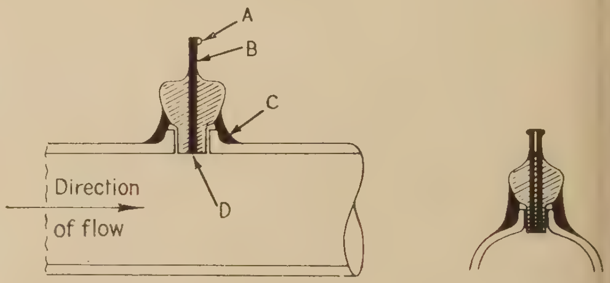


Fig. 1(*b*). Method of mounting bolometer in wall of shock tube

A, silver solder bead; *B*, tungsten electrodes; *C*, Picein wax; *D*, resistor.

THE AMPLIFIER

The desired output of the bolometer amplifier was a short-duration pulse of about 10 V peak amplitude. It was also desirable to detect the first few degrees change in temperature of the gas irrespective of the final temperature reached, in order to reduce timing errors. From these specifications the high gain amplifier shown in Fig. 2 was designed.

A wide band amplifier was necessary, capable of producing the specified output from an input of 100 μV. A resistance-capacitance coupled amplifier was used without any special pulse shaping circuits. A 6BR7 valve V_1 was used for the first stage because of its low noise characteristics. As the amplifier had to produce a positive output from a positive input three further amplifying stages V_2, V_3, V_4 were added,

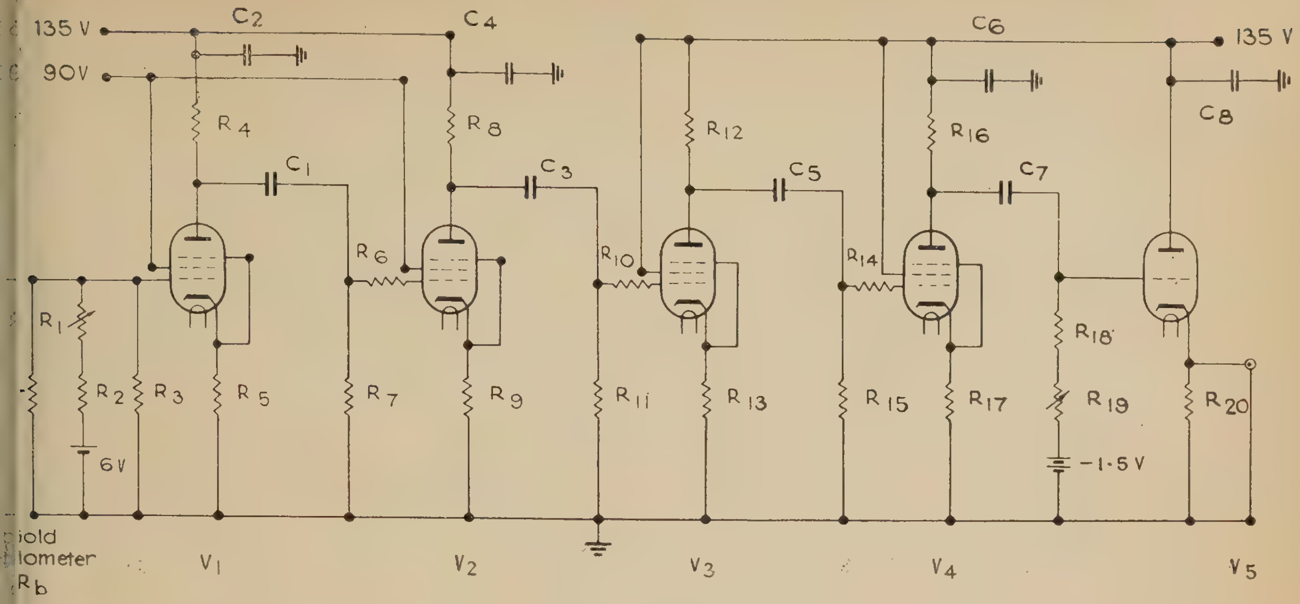


Fig. 2. Circuit of high gain amplifier

$R_1 = 500\ \Omega$
$R_2 = 470\ \Omega$
$R_3 = 1\ \mathrm{M}\Omega$
$R_4, R_8, R_{12}, R_{16} = 33\ \mathrm{k}\Omega$
$R_5 = 1{\cdot}5\ \mathrm{k}\Omega$

$R_6, R_{10}, R_{14} = 100\ \Omega$
$R_7, R_{11}, R_{15} = 470\ \mathrm{k}\Omega$
$R_9, R_{13}, R_{17} = 680\ \Omega$
$R_{18}, R_{20} = 22\ \mathrm{k}\Omega$
$R_{19} = 0{\cdot}5\ \mathrm{M}\Omega$

$C_1, C_2, C_3, C_4, C_5, C_6, C_8 = 0{\cdot}01\ \mu\mathrm{F}$
$C_7 = 68$ pF
V_1 = 6BR7
V_2, V_3, V_4 = 6AU6
V_5 = 12AT7

ch of valve type 6AU6. The output of V_4 was then ferentiated by the short time constant R–C coupling into output cathode follower V_5.

Because of mains conducted transients of large magnitude amplifier was operated from an independent power pply. "Minimax" 482 dry cells were used for the h.t. pply and a 6 V accumulator for the heaters. 6AU6 valves re used in order to reduce the bulk of the power supply d to give a high gain with the low value of high tension pply used.

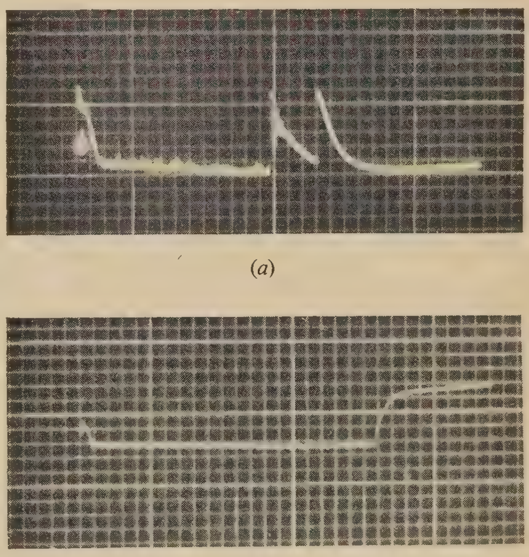
Ample signal was obtained when the gain of each amplify- stage was halved.

RESULTS

Three of the bolometers were sealed into a Pyrex expansion annel [Fig. 1(*b*)] so that the central detector was equistant from the first and third which were almost exactly n apart. Each detector was connected by coaxial cable to separate amplifier and the output signals were fed into a umont Model 303AH cathode-ray oscilloscope. Each tector gave a differentiated pulse the rise time of which was the order of 1 μs. The first detector was used to trigger e time base for the record and the other detectors gave ılses on this time base. The length of this time base was ried so that velocities between 200 and 3000 m/s could be easured. A typical record of a differentiated pulse is shown Fig. 3(*a*). When the differentiation stage was removed so at a stronger pulse was available a record such as Fig. 3(*b*) as obtained.

The third detector was placed in the expansion channel at out 5 cm from the end plate where the shocks undergo flexion. Thus in Fig. 3(*a*) there are two pulses due to the cident and reflected shock being detected by the same olometer. Sometimes weaker secondary pulses were bserved. These were also positive and were shown to be utputs from the first detector. These pulses cannot be due to the contact surface arriving at the detector because this should yield, if any, a negative pulse due to the driver gas having been cooled on expansion.

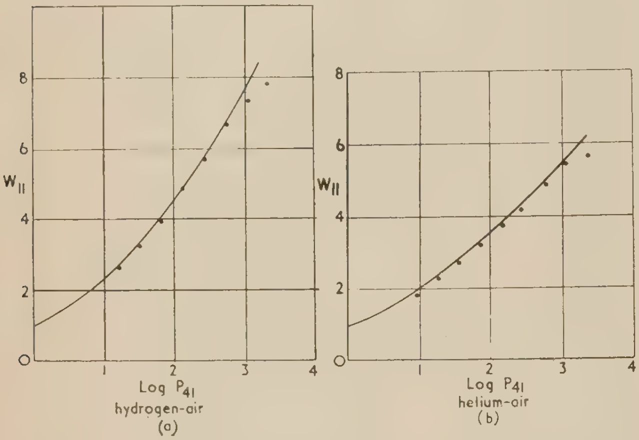
To assess the accuracy of this technique for measuring shock velocity a series of experiments was carried out using either hydrogen or helium as driver gas at a working pressure of about 4 atm. Shocks were sent into air (previously dried over calcium chloride) at 18° C the pressure of which was varied between 1 and 350 mm of mercury. This gave



(*a*)

(*b*)

Fig. 3. (*a*) Oscillograph trace showing the differentiated pulses. (*b*) Oscillograph trace showing an undifferentiated pulse diaphragm pressure ratios in the range of 2500 : 1 to 8 : 1 and so covered both the case of strong shocks entering low density gases and that of weak shocks in a higher density gas. The bolometers did not detect weak shocks in air at a pressure of 1 atm. A dibutyl phthallate oil manometer was used to set low pressures in the expansion channel.



Figs. 4(*a*) and 4(*b*). Plot of Mach number of shock front against the logarithm of diaphragm pressure ratio (theoretical). Observed values are shown as dots

Reference (2) gives a one dimensional mathematical theory of the shock tube and derives the relationship between W_{11} (the Mach number of the shock wave) and P_{41} (the ratio of the pressure p_4 of driver gas to the pressure p_1 of the gas to be shocked). This relationship has been plotted in Figs. 4(*a*) and 4(*b*) for the case of hydrogen-air and helium-air. The following values were used for the speed of sound at 0° C; air 330·6 m/s, hydrogen 1265 m/s, helium 970 m/s. These figures also show the experimentally determined Mach numbers of the shocks obtained from the cathode-ray oscilloscope records using the bolometer detectors.

It is seen that quite good agreement between theory and experiment exists. The experimental results are the mean of three determinations for each diaphragm pressure ratio. The times used for calculation of shock velocities could be measured to better than 2 μs. It is logical to assume that the experimental values will be slightly lower than theoretical because the theory of the shock tube assumes the gases to be perfect and to have constant heat capacities. It also ignores energy losses due to radiation or viscosity effects in the heated gas behind the shock front. A comparison of the value of the shock velocity determined between the first and second and the second and third detectors at a given diaphragm pressure ratio shows that over the length of 1 m very little attenuation of the shock has occurred. This is especially so when the density is low.

ACKNOWLEDGEMENT

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A projection spectrum comparator

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A new instrument for the comparison of spectrograms of 10 in. × 4 in. or other standard sizes, produces images in juxtaposition at a magnification of 20 on a 9 in. × 7 in. translucent screen. There are controls for focusing and for the longitudinal, transverse, and radial movements of the spectrum plates, and neutral tint wedges enable the brightness of the images to be equalized. An engraving tool is for the marking of selected spectrum lines, and a photographic attachment is used for the recording of comparison spectra. Wavelengths may be established by interpolation from measurements of known line separations with a micrometer attached to one of the carriages, or by comparison with standard spectrum maps by a beam splitter.

Spectrography is now established as one of the most important processes for the analysis of materials of many kinds, and its wide adoption by industry in the last thirty years or so is evidence of the searching power of the spectrum. Many instruments are now available, of high efficiency, for producing and recording spectra from the infra-red to the X-ray regions. The quartz spectrograph, for example, is to be found in almost every laboratory engaged in analysis, and by ingenious mechanical design the controls have been made suitable for speedy factory production tests.

The objects of spectrum analysis are usually to find out (1) whether a substance contains a given metal, or (2) what are the metals in a given substance. Both these questions may be settled more or less by inspection of the spectrum photographs produced by vaporizing the substance in an arc or, if suitable, by making it form one of the electrodes in a spark discharge and focusing the light on the slit of the spectrograph.

The spectra produced in these ways are usually so complex that it may be extremely difficult to determine the presence of lines due to some element, unless comparison can be made n another spectrum. Although a wavelength scale is ɔful this is only intended to give an idea of the approxi- te wavelength, and indeed those working continuously in onfined part of the spectrum recognize groups or isolated s at a glance. In spectrum analysis, therefore, for what- r changes there may be in a spectrum, or however pro- ed, comparison must be made in some way with a spectrum duced under known and standardized conditions.

From the early days of spectroscopy, and it must be nembered that about a century ago much valuable work s done in spectrum analysis, comparison spectra have been duced alongside the new spectrum to enable differences be seen. The small comparison prism attached to the slit y be seen on the earliest illustrations of spectroscopes and ctrographs and other arrangements utilizing diaphragms h openings covering adjacent portions of the slit have been d. Lockyer,(1) for example, used a slit with five channels his spectrograph in 1870 or earlier. The Hartmann phragm, with three openings, has been used for many rs. In those rather leisurely days, and indeed until the lespread adoption of spectrum analysis by industry, with its ramifications, it sufficed to produce spectra in juxta- ition; these often comprised a set consisting of spectra m the electrodes alone, the electrodes plus the sample, l possibly a third of the element sought for in the sample. The production of three spectra (or even two) with sufficient ntrol of the arc and electrical conditions to produce com- able spectra is not easy and could not be tolerated in the nditions obtaining in commercial laboratories. It is ssible to prepare one or a series of standard spectra of the bstance under examination, in which the wavelengths and ensities of the desired lines are established, and with table optical means the new spectra may be compared with standard (or with any plates exposed in the course of work).

A useful instrument, which has been known for nearly ty years, is the Judd Lewis comparator. This is a two-way croscope by which may be viewed simultaneously in the e eyepiece, objects placed beneath the two objectives. One the spectrum photographs is placed between two bars in e section, and the other similarly in the other section. By ning a milled head the two spectra are brought into precise justment. This instrument is widely used, but in common th most instruments using eyepieces can only be used by e person at a time, and consequently discussion in a group team is difficult. Also, due to the simplicity of design, it not easy to traverse a number of closely spaced spectra, in ich possibly the exposures or other conditions have been ried for the identification of ultimate lines or other purposes. The continual use of a microscope, with the conditions of ent examination, does often lead to eyestrain, although it is ue that experienced observers can avoid it. An image on screen is preferred, since both eyes can be used, and more an one person can see the picture at the same time, a decided vantage when searching for, and identifying, faint spectrum es.

A spectrum comparator of the projection type has been scribed by the writer(2) and the instrument which is the bject of this paper is of a similar type in which the images e received on a translucent screen, although in general of ite different design. In modern spectrographic laboratories ere is usually so much work in progress that a comparator, projector, or both, are in continuous use and it is desirable study the convenience of the operator, whose work can quite exacting.

In the projection spectrum comparator shown in Fig. 1 the screen is arranged to be about level with the eyes of a seated observer, and all controls are within easy reach. The two spectrum plates to be compared, which are placed on carriages in front of the observer, are each illuminated by a lantern producing a semi-field. A portion of each spectrum is projected via a projection lens, prism and mirrors, to a 9 × 7 in. screen, at a magnification of 20, and the images are in juxtaposition. There are two sliding shutters for isolating any portion of the image, a convenience when examining a narrow region. The two carriages run smoothly on rails, and are held together by a tension spring pulling one carriage against a rod mounted in the other. One end of the rod presses against a micrometer with a large drum reading to 0·0001 in. This micrometer serves two purposes, one of which is for bringing spectrum lines into coincidence, smoothly and without backlash. In addition the micrometer can be used to measure the distances between lines by bringing them successively up to a fine line on the screen, and by interpolation to arrive at the probable wavelengths.

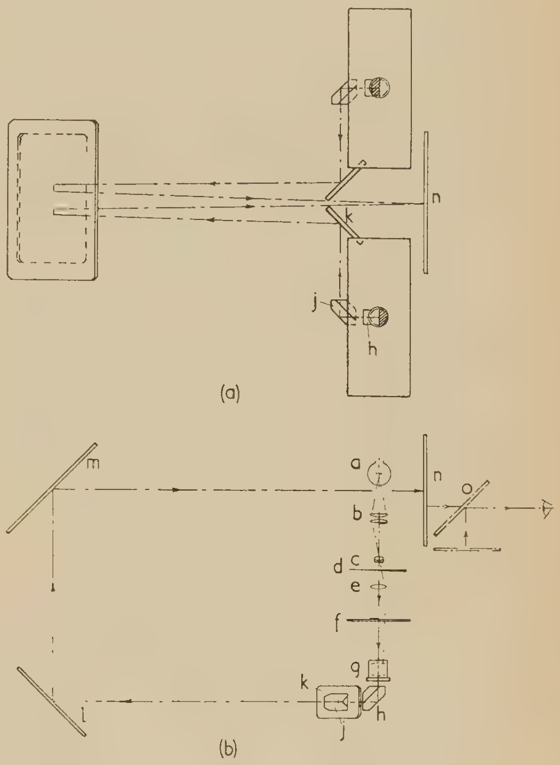

Fig. 1. Optical system of projection spectrum comparator: (*a*) plan, and (*b*) elevation

The carriages may be traversed easily and rapidly by means of a large handle operating a stainless steel cable drive, which is without sensible backlash. Each carriage has a mount which may be moved transversely to the length of the spectrum plates, so that a series of spectra in one plate, which may have been varied in respect of exposure or electrical conditions, or electrode content, may be compared rapidly and smoothly with a standard.

Attached to this mount is a frame on which the 10 × 4 in. plate is mounted, located by a metal strip with a chamfered edge, and clamped. This frame has a radial adjustment with a fine adjusting screw, so that the spectra may be aligned parallel to the longitudinal motion of the carriages.

Focusing of the Dallmeyer projection lenses is by finger touch on a lever protruding from each end of the base, and within easy reach.

An innovation on this type of instrument is the provision of a photographic panel with focusing screen which may be interchanged with the projection screen, for recording the comparison spectra in any desired region. This is useful for the illustration of reports and notes, especially for those to be sent outside the laboratory. For this photographic attachment there is a double dark-slide for 5 × 4 in. plates or films, and corresponding focusing screen, with a simple shutter in each projection system.

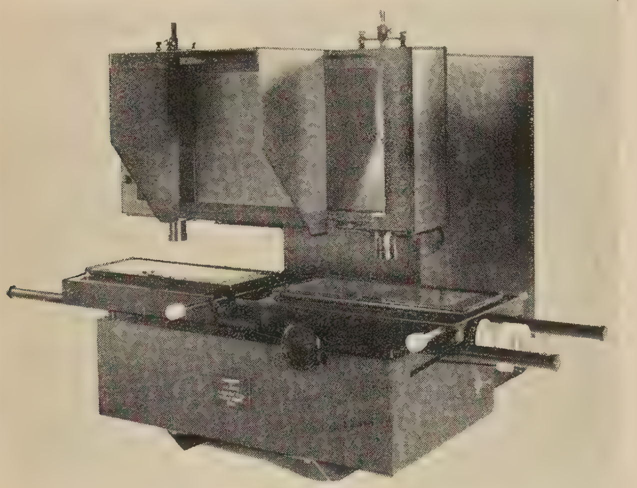

Fig. 2. Projection spectrum comparator

If, as is often the case, there is a slight difference in brightness of the lamps, or if the background fog of the spectrum plates is dissimilar, there may be a sensible difference in the brightness of the comparison images. This can be equalized by the adjustment in either or both beams of neutral tint wedges with transmissions varying from approximately 90 to 50%.

Figs. 1(*a*) and (*b*) are diagrams of the optical system in plan and elevation, in which, referring to one of the beams, *a* is a 24 W, 12 V lamp, and *b* a condensing system forming an image of the filament on lens *c*.

Half of the field of the condensers is blocked out, and an image of the "half-moon" is formed in the plane of the spectrum plate *f* by the lenses *c* and *e*. *d* is a neutral tint wedge.

The image, the diameter of which forms the dividing edg on the spectrogram, is projected together with the spectru lines, by the projection lens *g*, via the prisms *h* and *j*, a the mirrors *k*, *l*, and *m*, to the screen *n*.

The spectra, which are enlarged 20 times, are focused o above the other, with the edges just touching.

The optical system is designed so that the movements the images on the screen correspond to those of the plates, i all directions.

Fig. 2 is a photograph of the projection spectrum com parator, and Fig. 3 shows the photographic attachment i position.

An interesting feature shown in Fig. 1(*b*) is a semi-aluminize mirror *o* placed near to the screen. The purpose of this for the identification of spectrum lines by comparing th image on the screen with a spectrum chart or map marke

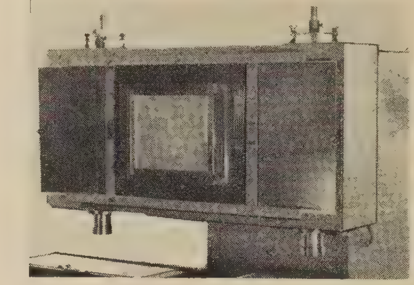

Fig. 3. Photographic attachment in position

with wavelengths, placed below the mirror. The observe then sees an image of the chart by reflection superimposed o the image seen directly through the mirror.

It is sometimes required to mark a line for reference an for this purpose there is an engraving tool in one of the beam which is operated by hand: the point of the tool is seen i position on the vertical line drawn on the screen and since is viewed under the magnification of 20 a line can be cut the gelatine with some precision.

The first model of the projection spectrum comparator i in use in the Metallurgical Laboratory of Bristol Aer Engines Ltd., whose requirements include the means marking lines, and the comparison with spectrum maps.

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A precision bath thermostat

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A thermostat is described for controlling the temperature of a 30 l. paraffin bath slightly above room temperature to a thousandth of a degree Celsius. An a.c. bridge is used in conjunction with a phase sensitive valve (originally developed as a frequency modulation detector).

of the two methods now being employed at the National sical Laboratory for the determination of the density of cury to one part in a million is to weigh the quantity of cury filling a 12·5 cm cubical silica box of known internal ensions.

he expansion coefficient of mercury is roughly $1\cdot8\times10^{-4}$ degree Celsius and hence an uncertainty of 5×10^{-3} °C ne measured mean temperature of the mercury in the box give rise to an uncertainty of about one part in a million he density determination. As this represents the overall uracy required it is desirable to measure the mean tem- ature to a thousandth of a degree Celsius. It is clearly practicable to measure the temperature of the mercury ctly, and as the time required for the box of mercury to h thermal equilibrium is several hours, it is necessary mmerse it in a constant temperature bath, controlled thousandth of a degree Celsius for many hours, re observations can be made. The temperature of mercury will then be very close to the temperature the surrounding bath; the latter can be measured ctly.

control system satisfying these requirements has n developed. It consists of a temperature sensitive in a Wheatstone bridge, fed from a 1000 c/s oscil- r, in conjunction with an amplifier and phase itive detector. The phase detector used was a uum tube originally developed as a frequency modu- on detector. As it is thought that this system may of more general application, a detailed description ows.

SIGN OF THE BATH AND CONTROL SYSTEM

he paraffin oil used as the circulating liquid is con- ned in a cubical brass box, of internal dimension m, lagged with 2 in. of cork, and to maintain a steady uniform temperature throughout such a volume, the owing conditions are necessary:

a) the element regulating the heat supply must be con- lled by the average temperature throughout the bath;

b) the heat supplied should be uniformly distributed oughout the bath;

c) the effects of variation of the external room temperature, space and time, should be minimized;

d) the controlling coil must be wound close to the heater with the object of reducing the time lag between the t input to the bath and the response of the controlling l, so minimizing hunting in the controlling system rner(1)).

he first two of these conditions can be met only approxi- tely in a bath which must provide space for other apparatus. the present system the controlling element is a 1000 Ω per coil, wound on the four vertical pillars of a Perspex me (see Fig. 1) surrounding the space to be occupied by the silica cube, and distributed evenly throughout the depth of the bath. The heater, developing about 2 W, is a manganin coil wound on an outer Perspex frame in close proximity to the copper winding and similarly distributed throughout the depth of the bath. By this arrangement the resistance of the copper coil is controlled by the average temperature of a large fraction of the oil of the bath, and the heat supplied is similarly distributed. The bath must, however, be stirred thoroughly to equalize the temperature throughout, and this is effected by four totally immersed pumps located in the four corners of the bath and driven by a pulsating air supply. This method of stirring is similar to that referred to in the Report of the National Physical Laboratory for 1923.(2) Oil is drawn into each pump on the suction stroke through evenly spaced holes in the lower portion of a vertical tube, and expelled through the upper section of a second tube, entry and exit of the oil being controlled by ball valves. Stirring is thus effected both horizontally and vertically.

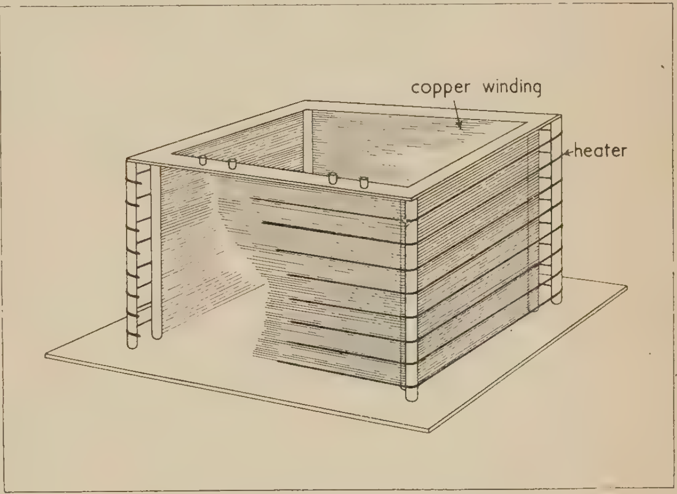


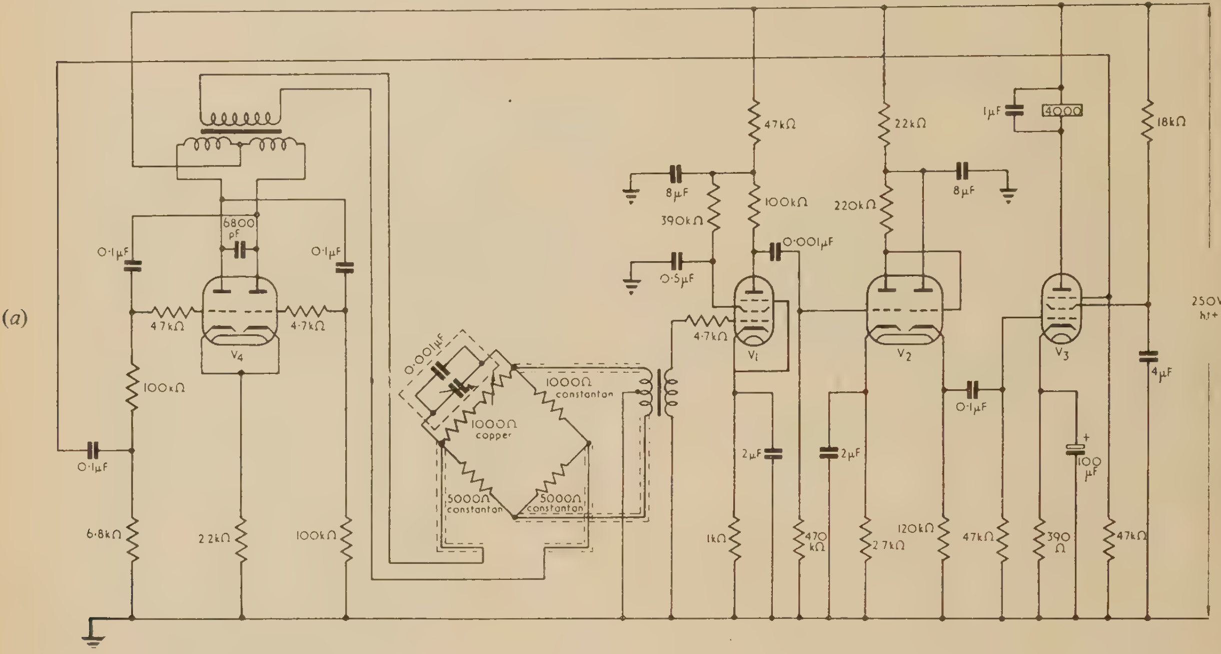
Fig. 1. Bridge and heater winding

Long term stability is not important in the present application, and the copper winding used as the controlling element has been found quite satisfactory. The copper coil forms the temperature sensitive element of a Wheatstone network in which the other three arms are constantan coils wound on Perspex formers and immersed in the oil bath itself to maintain them at constant temperature. The coils are non-inductively wound and a variable capacitor connected across the copper coil is used to compensate the residual reactances. A non-inductive resistance box is connected in series with one of the bridge arms to effect adjustment of the control temperature. All leads connected with the bridge are rigidly fixed to avoid changes in stray capacitances, and all leads emerging from the bath are screened to avoid pick-up.

ELECTRONIC CIRCUIT

A Hartley push-pull oscillator V_4 (see Fig. 2*a*) feeds the bridge network through an output winding, and also supplies, from a tapping on one of the grid leaks, the reference phase for the third grid of the phase detector valve V_3. The output from the bridge which undergoes a rapid phase change of 180° as the bridge passes through its balance point, is fed through a screened and balanced step-up transformer to a two stage resistance-capacitance coupled amplifier V_1 V_2, the cathode follower output from which feeds the first grid of V_3.

(*a*)



(*b*)

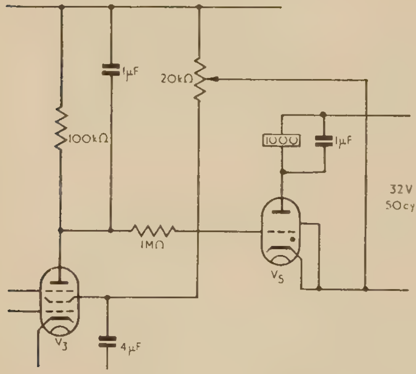


Fig. 2 (*a*) Circuit diagram of precision thermostat.

(*b*) Alternative anode connexions for use of thyratron.

V_1, EF86; V_2, ECC83; V_3, 6BN6; V_4, E88CC; V_5, 2D21.

V_3 is a type of valve originally developed as a frequency modulation detector. Initially the European type EQ80 was employed, but subsequently the American type 6BN6 was found to be more suitable. Only when the signal and reference voltages on the control grids of the valve are *both* sufficiently positive with respect to their cathodes do they conduct. The current through the valve is then sensibly independent of amplitude and varies linearly with the relative phases of the two signals from zero to a maximum fixed by the circuit conditions and the valve design. The type 6BN6 was found to be several times as sensitive as the EQ80 and gave a larger output current change. Both types require negligible power to feed their control grids. The 6BN6 has been fully described by Adler.(3)

The rapid phase change in the region of the balance point of the bridge, corresponding to a small change of temperatur in the controlling coil can thus give rise to a rapid change o current through V_3. Peak voltages of the order of ten ar required on the control grids of V_3, and in consequence th bridge operates at a point slightly removed from the tru balance point, depending upon the amplification provide by V_1 V_2. To feed the heating element it was found possib to operate a sensitive polarized Carpenter relay, shunted b a large capacitor, directly in the anode circuit of V_3, givin "on-off" heater control or to use the voltage changes develope across the anode load of V_3 to operate an a.c. fed thyratro (see Fig. 2*b*) with attendant relay, giving an approximatio to proportional control. The operating point of the Carpenter relay alone was found to drift rather too much over period of days to control to the required accuracy. Contro to ±0·001° C over periods of two days or more was onl achieved using a shield grid thyratron to operate the relay The "on-off" period of the heater was extremely shor generally being less than one second and scatter of temperature observations repeated at intervals of a few seconds was less than 0·001° C. This has been independently confirmed by recording continuously the anode current of th discriminator valve 6BN6, changes in which are directl proportional to changes of temperature of the controllin coil. It is intended later to use a magnetic amplifier in th le circuit of V_3 to obtain the full advantages of propor- al control. Further improvements contemplated involve use of two temperature sensitive windings in opposite s of the bridge.

PERFORMANCE

ne bath has been operated at a temperature approxi- ely 1·5° C above room temperature in a room controlled ±0·3° C. The performance over a fifty hour period of inuous operation using the thyratron operated relay is vn in Fig. 3. The recorded temperatures were measured

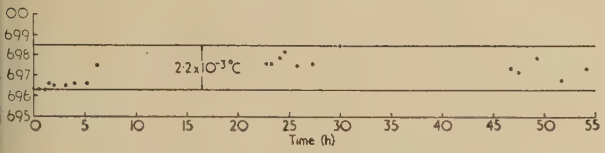


Fig. 3. Variation of bath temperature with time

n accuracy of two or three ten thousandths of a degree ius, with a platinum resistance thermometer placed with ulb at the centre of the bath. Resistances were measured Smith bridge type 3, described by Barber, Gridley and l$^{(4)}$ and modified as described by Gautier.$^{(5)}$

he temperature gradients in the bath have been investi- d by placing thermocouples in various positions and it been found that the bath must be stirred vigorously to inate temperature differences. The most troublesome hese are the vertical differences which may reach 0·15° C a depth of 20 cm if the bath is not stirred, even though mean temperature is maintained constant to a thousandth of a degree. Using the pumps mentioned above the mean difference between the top and bottom of the bath, averaged over a few minutes, can be reduced to two or three thousandths of a degree. Differences in temperature from side to side of the bath rarely exceed two thousandths of a degree, and both vertical and horizontal gradients can be further reduced by additional lagging and by operating nearer to room temperature.

ACKNOWLEDGEMENTS

The authors desire to acknowledge the assistance rendered by Mr. N. Conway of the Metrology Division Instrument Workshop who constructed the bridge and wound the heater coil, and of Miss H. M. Richardson who carried out observational work on the temperature gradients, also of Dr. A. H. Cook who initiated the work, advised on the construction of the bridge, and with whom they had much helpful discussion.

The work described above has been carried out as part of the research programme of the National Physical Laboratory, and this paper is published by permission of the Director of the Laboratory.

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An exposure calculator for isotope radiography

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[*Paper first received* 18 *December*, 1956, *and in final form* 24 *April*, 1957]

The factors affecting exposure time in gamma radiography using radon, ^{60}cobalt, ^{192}iridium, ^{170}thulium and ^{137}caesium are correlated so that for any stated conditions the exposure time is rapidly determined. While primarily designed for the radiography of steel the use of thickness conversion scales enables the calculator to be used to determine the exposure time for other materials.

e use of radiographic exposure charts or technique charts they are sometimes called, is well established in most ustrial radiographic laboratories, and while their use may perhaps be regarded as essential to the experienced radio- pher, it is generally accepted that they provide a valuable to securing consistent standards of radiographic quality. merous X-ray exposure charts have been published,$^{(1, 2)}$ d while these cannot in general be used with different types X-ray generating equipment, manufacturers of X-ray plant usually in a position to provide charts suitable for use in njunction with their own equipment. For simplicity, such rts are generally based upon a constant film speed, film nsity, tube milliamperage, focus-film-distance and material der examination, the user being left to make such correc- ns as may be demanded by any departure in his technique m the standard conditions employed in the preparation of chart. For this reason many laboratories find it more convenient to prepare their own X-ray exposure charts. Mention should, however, be made of exposure charts which have been devised$^{(3, 4)}$ in which, by the use of sliding scales a large number of variables are taken into account than are provided for in the conventional form of chart.

In the case of gamma-ray exposures, the number of variables at the disposal of the operator are somewhat more restricted, and for this reason their correlation is more straightforward. Thus while the simpler gamma-ray exposure charts$^{(5, 6)}$ are similar to those used in X-ray work, radium and radon exposure calculators$^{(7, 8)}$ of more universal application have been designed in the form of linear or circular slide rules. While such calculators are of undoubted value and have found extensive use in laboratories employing radium or radon, with the increasing use of the artificially prepared radioactive isotopes, the need for an isotope exposure calculator has for some time been apparent.

The calculator* which forms the subject of this paper was in consequence developed by the British Steel Castings Research Association (B.S.C.R.A.) with a view to meeting the requirements of steel foundry radiographic laboratories for gamma-radiography employing ^{60}cobalt, ^{192}iridium, ^{137}caesium, ^{170}thulium and radon sources.

THEORETICAL CONSIDERATIONS

In the design of a universal gamma-ray exposure calculator it is convenient to consider scale construction under the following three functional headings:

(*a*) Exposure determination,
(*b*) Source decay determination,
(*c*) Thickness conversion determination (for materials other than steel).

(*a*) *Exposure determination.* The exposure determination equation is similar to that used by Kahn, Imbembo and Bland(8) but slightly modified to satisfy the requirements of all types of gamma-radiography and to take cognisance of film density. Based on the exponential absorption law it can be written as:

$$\log E_F = \log F + \log E_0 + (\theta/m) + 2 \log d - \log M.$$

where E_F = exposure time with a film of factor F.
F = film speed factor.
E_0 = exposure time to produce a fixed density with zero steel thickness.
θ = thickness of material in inches.
m = gradient of the absorption (thickness versus log exposure) curve.
d = source to film distance, in inches.
M = source strength, in millicuries.

With the exception of the (θ/m) term, all other terms are additive or subtractive as logarithms and can therefore be made the basis of a slide rule type of calculator. The θ/m term corresponds to the steel thickness scale and is linear when the absorption (thickness versus log exposure) curve is linear, and varies from linearity as the absorption curve so varies. The source to film distance scale requires twice the logarithmic cycle length of the other logarithmic scales, which correspond to film factor, source strength and exposure time.

Since film density is a function of the logarithm of the exposure time, a linear scale corresponding to film density can be used in place of the term $\log E_0$, which otherwise would be a fixed datum point corresponding to a particular gamma-ray source for a particular film density.

The expansions of the steel thickness and film density scales are determined by the value of m and γ respectively, where γ is the slope of the film density versus log exposure curve of the film, that is m is a function of the absorption characteristics of the radiation of a particular source and γ is a function of the contrast properties of a particular film.

(*b*) *Source decay determination.* Owing to the relatively rapid decay of radon and iridium it is desirable to include scales for determining the decayed strength of the source at the time of use. Radioactive decay is an exponential function of time and hence can be conveniently measured by a linear time scale laid off against a logarithmic scale of source strength. The expansion of the time scale is dependent on the half-life of the particular source and the units of the time scale are such that the period of the half-life is equal to the halving value of the logarithmic source strength scale, i.e. the scaler length of the logarithm of 2.

(*c*) *Thickness conversion determination* (*for material other than steel*). Although there are some anomalies, e.g. the toe portion of the steel thickness versus log exposure curve for ^{170}thulium(9) or where the wavelength of the incident radiation corresponds with an absorption edge in the material radiographed, the exposure time for two different materials is equal as long as the product of density and thickness is the same, i.e.

$$d \times t = d' \times t'$$

or

$$t = t' \times (d'/d)$$

where t is the thickness of steel of density d equivalent to a thickness of t' of material of density d'.

Thus by laying off the two variables thickness and density on equal cycle logarithmic scales the thickness of any given material of known density to be determined in terms of the equivalent thickness of steel.

EFFECTUAL DATA

The preparation of an exposure calculator of the type described, required the availability of practical data concerning the following relationship:

(*a*) Exposure data in the form of steel thickness versus log exposure curves for each type of source.
(*b*) Sensitometric data in the form of film density versus log exposure curves for representative X-ray films.
(*c*) Film speed data concerning the selected X-ray films.

(*a*) *Exposure curves.* Steel exposure curves were determined for the sources ^{60}cobalt, ^{192}iridium, ^{137}caesium, ^{170}thulium and radon, under the conditions shown in Table 1. Film development was standardized at 5 min at a temperature of 68° F using Kodak D-19b developer. In each case the film was exposed to a density of 2·0.

Table 1. *Determination of steel exposure curves*

Radiation source	*Source-film distance (in.)*	*Film used*	*Lead screen thickness (in.)*	
			Front	*Back*
^{60}cobalt	20	Industrial *C*	0·004	0·010
^{192}iridium	20	Industrial *C*	0·004	0·010
radon	20	Industrial *C*	0·004	0·010
^{137}caesium	20	Industrial *C*	0·004	0·010
^{170}thulium	10	Industrial *B*	0·002	0·020

The exposure curves so obtained were then corrected to unify the source-film distance and the source strength, and replotted as in Fig. 1 which indicates the relative exposure times for ^{60}cobalt, radon and ^{192}iridium under these standard conditions. The expansion of the steel thickness scale was then obtained by projecting the intercepts of various steel thicknesses on the exposure curve onto the log exposure time scale of the abscissa. By making the log exposure time-scale cycle length equal to that required for the calculator, the derived steel thickness scale is that required for the calculator, and since each exposure curve is for the same standard condition the relative datum point of each steel thickness scale is also obtained.

(*b*) *Film characteristic curves.* Because of the variations in shape and slope of the sensitometric curves of different types of X-ray film, a separate film density scale is required for each type of film. These differences are, however, small compared with the batch variation in speed of X-ray film and for this reason it has been found sufficiently accurate to employ a single film density scale.

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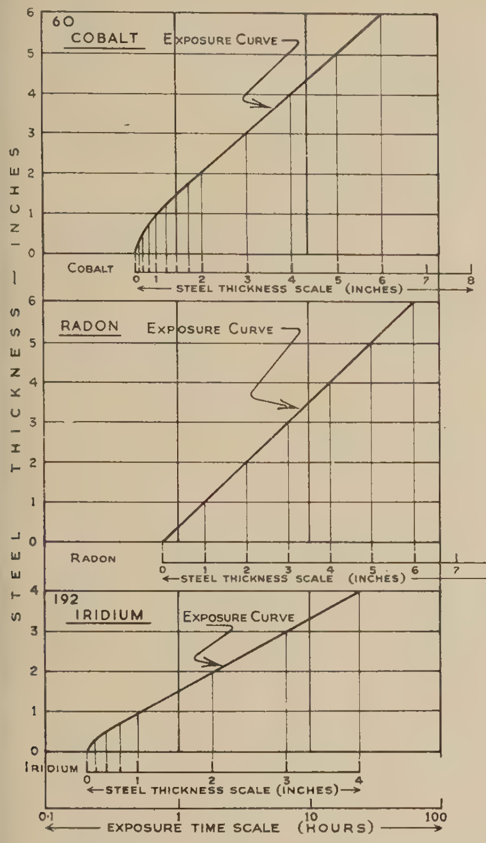
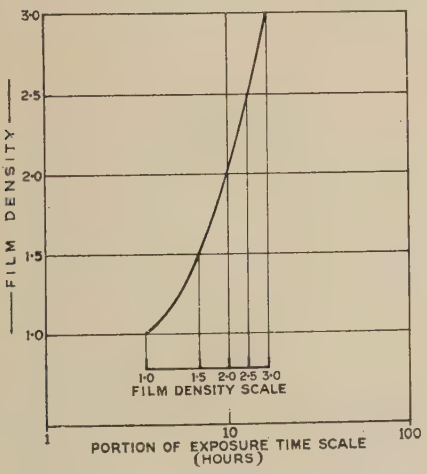
* This Exposure Calculator is protected by copyright in the United States of America and in all countries which are signatories to the Berne Convention.

e expansion of this scale, Fig. 2, was therefore derived the sensitometric, film density versus log exposure time, of a film of average contrast in the same manner as the nsion of the steel thickness scales were obtained from xposure curves.



g. 1. Derivation of steel thickness scales from exposure curves

A, ^{60}cobalt; *B*, radon; *C*, ^{192}iridium.



g. 2. Derivation of film density scale from sensitometric curve

) *Film speed factors.* While the relative film speed ors *F* are strictly speaking, contingent on the density value hich the comparison is made, the batch variation in speed or practical purposes sufficient to outweigh this consideration. Film speed factors in terms of the relative exposure times to produce a film density of 2·0 under standard exposure conditions, were therefore, determined for development times of 5 min and 8 min at 68° F using Ilford ID. 19 developer. For this purpose the film speed ratings given by each film manufacturer were examined in conjunction with independent measurements made both by the Association and by other laboratories. While the figures so determined were by no means consistent with one another, representative values were obtained. These are shown in Table 2. The film factors shown in this table may be regarded as the exposure time in minutes required to produce a gross film density of 2·0 at a source-film distance of 24 in., using an unshielded source of 1 000 Mc of ^{60}cobalt with lead screens of 0·004 in. in front of and 0·010 in. behind the film.

Table 2. *Representative values of film speed ratings*

X-ray film		*Film factor based on development time of:*	
Make	*Type*	*5 min at 68° F*	*8 min at 68° F*
Ilford	Industrial *G*	9	7
	Industrial *B*	19	14
	Industrial *C*	108	70
	Industrial *F*	180	120
Kodak	Kodirex	8	6·5
	Industrex *D*	19	14
	Crystallex	55	40
Eastman Kodak	M	158	116
	A	49	40
	F	20	18
	K	8	6·5
	No-screen	13	11
	Blue brand	20	18
Gevaert	Structurix *D*10	16	12
	Structurix *D* 7	67	47

THE B.S.C.R.A. CALCULATOR

The calculator developed along the lines described is shown in Fig. 3 (obverse), and Fig. 4 (reverse). It consists essentially of two slides each carrying two scales and mounted between two fixed scales. Correlation of the scales is facilitated by means of a cursor. The upper slide *A* is itself double-faced. Both faces carry a source film distance scale, scale 3, and while one face carries the steel thickness scales for ^{60}cobalt and ^{192}iridium, the other carries the steel thickness scales for ^{137}caesium, ^{170}thulium and radon (scale 2). The orientation of the scales of the various variables is obtained by setting the calculator so that the conditions defining the film factor are met, namely that for a film density of 2·0 a source strength of 1 000 mc and a source film distance of 24 in., the film factor number corresponds to the time in minutes for zero steel thickness on the ^{60}cobalt scale.

The relative datum point of the steel thickness scale for each isotope is obtained as indicated in the previous references to Fig. 2.

The determination of an exposure time for a given set of conditions is carried out as follows:

(1) The appropriate face of scale *A* is located to show the steel thickness scale of the isotope to be used.

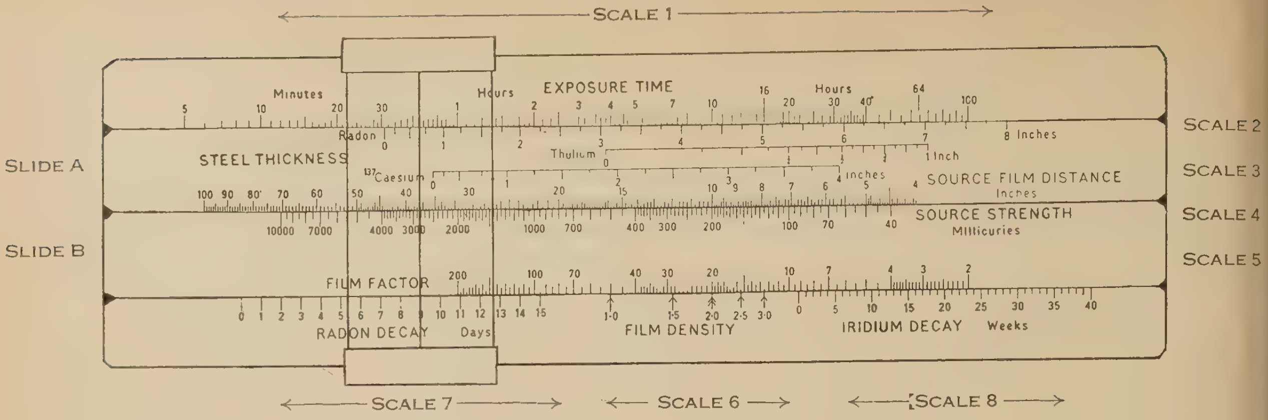


Fig. 3. The B.S.C.R.A. exposure calculator (obverse)

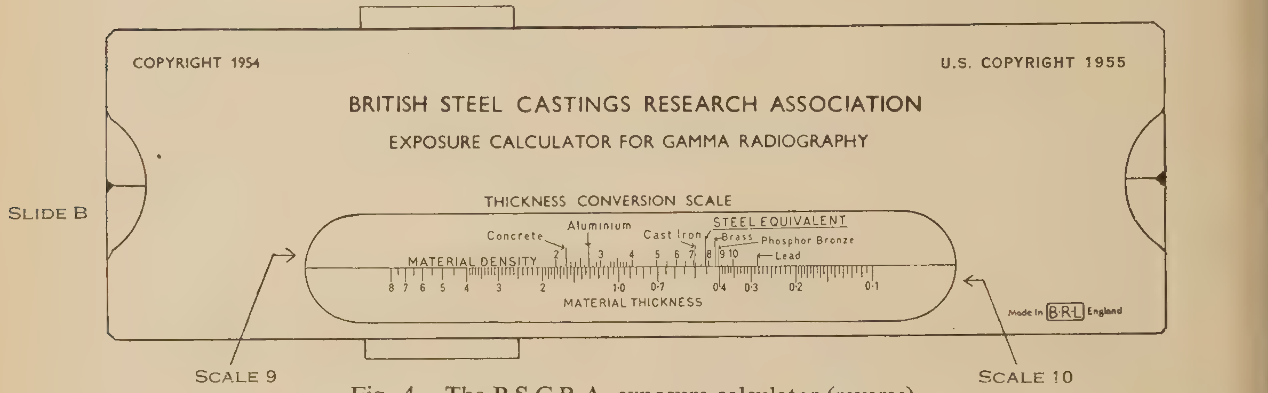


Fig. 4. The B.S.C.R.A. exposure calculator (reverse)

(2) The Film Factor (Table 2) is set against the required Film Density.
(3) With slide *B* in this position the Source-Film Distance is set against the Source Strength.
(4) The exposure time is read off against the steel thickness on the steel thickness scale of the isotope in use.

For overnight or week-end exposures (indicated on the exposure time scale at 16 hours and 64 hours respectively), the Film Factor and Film Density scales are set as before while the steps (3) and (4) above are reversed so that the final reading is that of Source-Film Distance.

Source decay scales. The decay scales, scale 7 for radon and scale 8 for ^{192}iridium, are located in line with the Film Density scale. These scales are used in conjunction with the Source Strength Scale 4, the cursor facilitating correlation between them. The determination of exposure time by the calculator makes no allowance for source decay during the course of a long exposure. Since this effect is appreciable in the case of radon sources, account should be taken of the decay by using the mean value of the source strength during the exposure time in exposure of greater duration than 24 h.

Material thickness conversion scales. These scales, material density scale 9 and material thickness scale 10, are located on the reverse side of the calculator and viewed through a window cut in the base. These scales are reversed relative to each other so that the thickness of steel equivalent to any thickness of another material may be read off directly.

The material density scale is in units of grams per cubic centimetre, while the material thickness scale may be read off as centimetres, inches or any other unit of length so long as the same units are employed throughout.

ACKNOWLEDGEMENTS

The experimental data upon which the Calculator is bas were prepared and made available by the Radiologic Department of the Armament Research and Develo ment Establishment, Woolwich, and the Association tak this opportunity of acknowledging the help so afforded b the Establishment, and in particular by Mr. R. Halmsha and by the late Mr. C. Croxson.

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Laboratory and workshop notes

ethod for the measurement of solid film thicknesses in the 5 to 30 micron range

/ Garry Thomson, M.A., Scientific Department, National Gallery, London

[*Note first received* 14 *January, and in final form* 26 *February*, 1957]

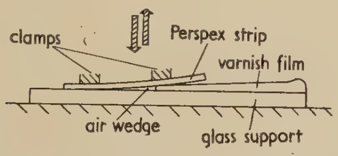
ip of glass or Perspex, placed over a cut edge of the film se thickness is required, is clamped to this edge and to support, the two clamps being about 15 mm apart. n the number of fringes in the air wedge thus formed veen slip and support the thickness of the film can be ined.

ıe method can be used in two ways:

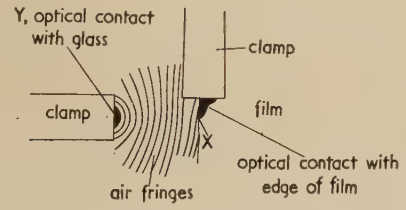
) For a transparent glossy film on glass, thickness ours over the whole film can be made visible by first platinizing the glass.* The thickness at any point on dge is obtained as described below.

) The thickness of any solid and coherent film may be ined by cutting an edge at the point where the thickness quired.

either case the measurement is made as follows. About n of the edge of the film is removed with a razor blade straight edge. A Perspex slip (about 1 mm thick) is ed over the slide and clamped firstly on the uncoated s support and secondly over the cut edge of the film, cing optical contact in both cases (Figs. 1 and 2). Toolcers' clamps are suitable, and one of them is conveniently d to a base in such a way that the glass support is held 1 the film surface horizontal.



ig. 1. Diagram in vertical cross-section of film preared for measurement (with heights exaggerated). The m is illuminated and viewed from above, as shown by the two arrows


Y, optical contact with glass
clamp
clamp
film
X
optical contact with edge of film
air fringes

ig. 2. View from above under monochromatic light. he number of fringes between *X* and *Y* gives the thickness of the film at *X*

he arrangement is examined under vertical, parallel, reflected, monochromatic light with a travelling microscope at a magnification of about ×20. Between the two contact areas under the Perspex slip can be seen a series of fringes caused by interference between the lower surface of the Perspex and the glass support (Fig. 2). The thickness of the film at *X* is found by counting the number of these fringes between *X* and *Y*, the contact area on the glass. Since the fringes are in air, the thickness is equal to $n\lambda/2$ (where n = number of lines between *X* and *Y*, λ = wavelength of illumination).

The film is, of course, compressed under the clamp, but not at *X*, and this can quite easily be verified by noting the absence of any distortion at *X* of the film contours over a half-platinized support.

Small detached fragments of film are measured on glass in the same way as adhering films, except that optical contact must be ensured on both sides of the fragments. In these cases a glass slip will be found easier to manipulate than a Perspex one. A piece of a microscope slide is of suitable thickness: very thin glass will cast its own interference fringes over those to be measured.

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* Merton, T. *Proc. Roy. Soc.*, *A*, **189**, p. 309 (1947).

A revolution counter for high-speed shafts

By J. A. Sanderson, A.M.Brit.I.R.E., Mechanical Engineering Research Laboratory, Thorntonhall, Glasgow

[*Note received* 15 *January*, 1957]

Revolution counting in rotating machinery is an ever-recurring problem which is resolved by using photoelectric, capacitive and electromagnetic methods, the latter being preferred for its simplicity and reliability. At high speeds, however, the need for a plug or projection on the shaft introduces balancing difficulties. The method to be described allows a satisfactory mechanical design to be achieved with the knowledge that the revolution counting equipment can be added without further interference with the shaft.

The stationary shaft is stroked along its axis by a permanent magnet and a tape recorder head is placed at a distance of 0·0005 in. from it so that rotation of the shaft will produce a pulse for each revolution. The output may be taken to an oscilloscope and the speed calculated from the time-base frequency, or it may be connected *via* a step-up transformer to a Dekatron counter and the speed found by timing. Using a 1 : 35 transformer an output of 50 mV can be obtained at 6000 rev/min on a ¼ in. shaft.

The method is also applicable to existing machines where the end of the shaft only is available: in this case the shaft is stroked radially and the pick-up mounted in an appropriate position. So far the method has worked up to 60 000 rev/min and while the magnetization is expected to decrease with time a specimen of steel has retained a pulse for some three months.

The work described has been carried out as part of the research programme of the Mechanical Engineering Research Board of the Department of Scientific and Industrial Research. This note is published by permission of the Director of Mechanical Engineering Research.

Correspondence

A simple arrangement for obtaining optical transforms of crystal structures

Mr. Aravindakshan's note, published on p. 250 of the June 1957 issue of this *Journal*, serves a useful purpose in drawing attention to the optical-transform work that can be accomplished reasonably accurately with a single lens, and anyone who has a good highly corrected lens might well make use of his device. In general, however, the use of a single lens does not lead to any great simplification. Lenses corrected for spherical aberration in the symmetrical position are not easy to come by, and since they need to be of twice the power of each of the separate lenses in Hanson and Lipson's instrument, they would be more expensive. Anyone, therefore, who is contemplating the use of the device would be best advised to use the two-lens instrument which, at the same time, satisfies the ideal condition that the mask should be placed in a parallel beam of light.

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University of Manchester.

H. Lipson
[14 July, 1957]

Avoiding the need for dividing units in setting up electronic differential analysers

Dividing units are generally inconvenient to use since they are always inaccurate for small inputs and frequently can only handle inputs of one sign.(1) On mechanical differential analysers quotients may often be generated with integrators alone(2, 3) but the same techniques cannot be adapted to electronic analysers as these can only integrate with respect to physical time, T. This note shows how the need for dividers in electronic analysers can usually be avoided by introducing an auxiliary (parametric) variable. The procedure requires one extra integrator, and, in more complicated cases, a number of extra multipliers. Since multipliers are more accurate and more readily available than dividers the method should often be worthwhile.

Consider the non-linear differential equation

$$\frac{dy}{dx}=\frac{x(ax+by+c)+d}{y(a'x+b'y+c')+d'} \qquad (1)$$

(arising in astronomy and elsewhere), for which the straightforward correspondence between problem variables (lower case letters) and machine variables (capitals) is:

$$y \to Y,\ x \to T$$

With this representation a divider is required to set up the equation and it will then be impossible to study the solutions in any region where the denominator of (1) vanishes. This difficulty may be avoided completely by using the identity $dy/dx = (dy/dt)/(dx/dt)$ and writing (1) as

$$\frac{dy}{dt}=k[x(ax+by+c)+d] \qquad (2)$$

$$\frac{dx}{dt}=k[y(a'x+b'y+c')+d'] \qquad (3)$$

where t is an auxiliary variable and k is any constant.

If, now, machine time T is used to represent the variable no divider is required although one extra integrator is needed. The explicit solution of the original equation (1) is obtained by displaying $Y(T)$ against $X(T)$ (instead of using a time base waveform). The magnitude of the constant k determines the speed at which the solutions are plotted whilst its sig determines the direction of integration.

It may be that the individual equations (2) and (3) are unstable so that the results as viewed in the (X, T)- o (Y, T)-planes are very sensitive to hum and noise. The plo of the solution trajectories in the (X, Y)-plane, however, wi not show the effects of such additional instability.

The same principle may be extended to second-ord differential equations such as

$$\frac{d^2y}{dx^2}+\left[f(x)+\frac{A}{x^2}\right]y=0 \qquad (4)$$

which is a modification of Bessel's equation occurring nuclear scattering theory. The division by x^2 may be avoid by writing (4) as

$$\frac{dx}{dt}=kx^2, \quad \frac{dy}{dt}=kx^2y'$$

and

$$\frac{dy'}{dt}=-k[A+x^2f(x)]y \qquad (5)$$

and then using the correspondence: $x \to X$, $y \to Y$, $y' \to$ $t \to T$. The cost is greater in this case since as well as t extra integrator, an extra multiplier is needed to form t product x^2y'. Furthermore, the function generator mu now be a generator for functions of machine variabl (rather than of time).

The general case of an nth-order differential equation ma be treated by considering the canonical form of the equatio namely,

$$\frac{dy_i}{dx}=F_i(y_1, y_2 \ldots y_n; x) \quad i=1, 2 \ldots n \qquad (6)$$

Suppose that each right-hand side F_i can be expressed as

$$F_i(y_1, y_2 \ldots y_n; x)=\frac{f_i(y_1, y_2, \ldots, y_n; x)}{g_i(y_1, y_2, \ldots, y_n; x)} \qquad (7)$$

where the functions f_i and g_i can be formed from the variable $y_1, y_2 \ldots y_n$ and x without using dividers. This separatio may not always be possible [for example, if $F_1 = \cos (x/y)$ but on the other hand a number of the g_i will usually b mere constants. Assuming the decomposition (7) the parametric variable t is introduced by writing (6) as

$$\frac{dx}{dt}=k\prod_{j=1}^{n}g_j(y_1, y_2, \ldots y_n; x) \qquad (8)$$

and

$$\frac{dy_i}{dt}=kf_i(y_1, y_2, \ldots y_n; x)\prod_{j\neq i}^{n}g_j(y_1, y_2, \ldots y_n; x) \qquad (9)$$

These equations may be set up without dividers by using th correspondence: $x \to X$, $y_i \to Y_i$, $t \to T$. The excess o pliers now required over p, the number of dividers ally needed (when $x \to T$), depends on the particular em but is likely to be at least

$$m = n + 2p - 5 \quad \text{if } p > 1 \qquad (10)$$
$$m = n - 2 \quad \text{if } p = 1$$

ll also be necessary to replace function generators for ions of time only, by generators for functions of machine bles, as in the second example above.

e foregoing treatment remains valid even if the scaling ant k is itself a function of all the variables. Simple functions are easy to generate and may be used conntly to change the scale when the speed of integration the trajectories varies too greatly.

s obvious that in a complicated problem this technique voiding division is only useful if ample multipliers are available or if it is very important to examine the solutions in the region of a vanishing denominator. For simpler problems, on the other hand, the advantages can be considerable.

Wheatstone Physics Laboratory, King's College, London. M. E. FISHER
[26 February, 1957]

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New books

iques Générales du Laboratoire de Physique. Vol. 1, 2nd Ed. Edited by J. SURUGUE. (Paris: Centre National le la Recherche Scientifique, 1955.) Pp. 671. Price 2400 *f.*

work by eleven authors deals with the arts and crafts of imental physicists. The first volume, of which the d edition has now appeared, covers subjects such as al principles of apparatus design and construction, blowing, vacuum technique, production and measure of high temperatures, optical work, light sources, filters hotocells, recording, voltage and current regulation, and y the electronics applicable to amplifiers.

e present work invites comparison with Strong's Modern ical Laboratory Practice and Kohlrausch's Praktische ik. It occupies a place intermediate between these in on the one hand it contains lucid statements of under principles and shows the ways of masters of their crafts er than of amateurs in a hurry) and on the other it does o as far into details of methods and the critical evaluation y observations.

though of small print and, page for page, containing ps one-third more words than Strong's book, I find it to the eyes and illuminated by many line drawings of clarity. The uniformity of these drawings testifies to ork of the Editor, but so, unfortunately, does the uniform quacy of the bibliography which enumerates principal ooks and periodicals, but without detailed reference. interesting to observe that out of thirty-one different s listed, sixteen are in the English language, only one in nan, the remainder in French.)

viously a book of not quite 700 pages cannot be anye near exhaustive, and therefore cannot be expected to ny specialist much new about his own field, but to an ested outsider it is a fascinating and instructive statement hat, to a specialist, appears to be the basic and essential iderations of his art.

dipping into the pages at random here and there this wer cannot but regret that this book did not come his in his student days, when the memory of his French lessons had not yet faded. I am sure I would have almost playfully read myself into scientific French, and consequently have expanded and effortlessly maintained a stock of essential linguistic knowledge. O. KANTOROWICZ

Notes on applied science No. 14. Photometry of telescopes and binoculars. (London: Her Majesty's Stationery Office, 1955). Pp. iv + 17. Price 2*s.* 0*d.*

Work carried out at the National Physical Laboratory on the photometry of optical instruments was described by J. Guild in the Proceedings of the London Conference on Optical Instruments, 1950, including the measurement of axial light transmission, veiling glare, and field brightness. This more recent booklet describes very clearly the construction and method of use of apparatus for making these measurements on telescopic instruments. Theoretical considerations are reduced to a minimum, but sufficient practical details are given to enable even the most modestly equipped laboratory to produce the apparatus, and take measurements on it. C. G. WYNNE

Notes on Applied Science No. 13. Standard capacitors and their accuracy in practice. (London: H.M. Stationery Office, 1956.) Pp. iv + 10. Price 1*s.* 3*d.*

This booklet prepared by the National Physical Laboratory gives a good assessment of the effects of (1) construction (design), (2) the ambient atmosphere, and (3) the method of use, on the accuracy of air and mica capacitors. The diagrams illustrating the composite nature of capacitors and the data showing the magnitude of known change of any of these factors are useful, particularly to industrialists.

A greater emphasis on the essential facts for the correct design and method of use of capacitors to give the highest accuracy of capacitance, together with some assistance to the industrial user on how to select a stable, well designed capacitor, would have enhanced the value of the "note" considerably. K. A. G.

Notes and comments

The Education of Physicists in Universities and Colleges of Technology

In November 1956 a conference was held on "Degree and diploma courses in applied physics." The conference was organized jointly by the Institute of Physics and The London and Home Counties Regional Advisory Council for Higher Technological Education and was held at the Institution of Electrical Engineers, London. The aim of the conference was to provide an opportunity for the discussion of the question of courses in applied physics and the need to develop them in a manner differing from that of a university honours degree course while, at the same time, demanding similar intellectual ability. It is hoped thereby to produce men and women with a knowledge of fundamental physical principles and an aptitude for the application of physical knowledge, in order to meet the needs of industry for both research and development.

The conference high-lighted many of the problems and differences of opinion which must arise where such schemes are discussed and it was felt that, because of the interest which this subject has stimulated, the proceedings of the conference, in a slightly edited form, should be made generally available. This has now been done and the proceedings, reprinted from the *Bulletin* of The Institute of Physics and under the above title, can be obtained from The Institute of Physics, 47 Belgrave Square, London, S.W.1. Price 6*s*.

British Computer Society

Some months ago a working party examined a proposal to form a national society to meet the need for a forum for the exchange of information between the people concerned with computers and automatic data-handling techniques in their scientific, engineering, business and other aspects, and agreement has now been reached to form a new body to be called the British Computer Society. The London Computer Group which was formed in 1956 and which has so far catered primarily for business interests has agreed to take part in the formation of the new Society and to add its resources to it; all existing members of the Group will automatically become members of the new Society, the objects of which are: (*a*) To provide an organization for those interested in and to further the development and use of computational machinery and the techniques allied thereto; (*b*) To facilitate the exchange of information and views and to foster well-informed public opinion on this subject; (*c*) To hold conferences and meetings for the reading of papers and delivery of lectures; (*d*) To publish a Journal, and other information for the benefit of its members.

It is intended to incorporate the Society as a company limited by guarantee. A provisional Council has been formed with the following membership: A. D. Booth; E. E. Boyles; A. J. Bray; E. C. Clear Hill; A. S. Douglas; R. G. Dowse; F. S. Ellis; H. W. G. Gearing; A. Geary; C. G. Holland Martin; D. W. Hooper; E. N. Mutch; R. E. Stevens; F. Yates.

The Society intends to form regional and specialist groups, and at the outset will set up a Business group and an Engineering and Scientific group.

All those interested in obtaining further information should apply to the Honorary Secretary, The British Computer Society, 29 Bury Street, London, S.W.1.

Errata

In the description of Muirhead instruments which appeared on page 171 of the April issue of this *Journal* the impedance single meter referred to in line 4 should read "impedance angle meter." Under the heading *Low frequency phasemeter* the description of this instrument is correct as far as "0·5 to 10 kc/s." From then onwards to the end the description refers not to the phasemeter but to the impedance angle meter.

In the paper by Dr. A. C. Rose-Innes which appeared on pp. 276–278 in the July issue of this *Journal* the following legends should appear below the figures: Fig. 1. Basic reflection spectrometer; Fig. 2. The 3 cm-band apparatus; Fig. 3. The frequency modulation method. (*a*) No electron absorption; (*b*) electron resonance absorption; Fig. 4. Saturated amplifier. (*a*) Normal Class A amplifier; (*b*) saturated amplifier; Fig. 5. Cyclotron resonance in germanium at 4·2° K; Fig. 6. Rise and decay of cyclotron resonance absorption of heavy hole in germanium at 4·2° K.

British Journal of Applied Physics

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Some new electrical and magnetic ceramics*

By G. Campbell, B.Sc., A.R.T.C., F.R.I.C., A.M.I.Mech.E., The Plessey Co. Ltd., Towcester, Northants.

These materials have been conveniently classified as insulator, conductor, ferroelectric and ferromagnetic ceramics. The functions of insulator and of conductor ceramics are readily understood and the underlying theory of conduction is briefly outlined. The ferroelectric and ferromagnetic classes are less widely appreciated: the analogies and the differences in these groups are discussed. The wide range of applications for these materials is indicated and some ceramics of particular interest to the electrical engineer and physicist are described more fully. These include ferroelectrics based on barium titanate for ceramic capacitors, piezoelectric transducers, dielectric amplifiers and memory devices. Other important ceramics are ferromagnetics based on soft magnetic ferrites for radio and television components, very high-frequency applications, magnetostrictive transducers, microwave components and memory devices together with ferromagnetics based on hard magnetic ferrites. Electronic devices and equipments of the future may use "solid" circuits made from various ceramic materials inert to moisture and capable of operating at relatively elevated temperatures.

THE TERM "CERAMIC"

otter of early times, while plying his trade, little knew a variety of materials he was pioneering, now grouped the word "ceramics," which incidentally can be pro- ced either with a soft or hard "c" and either pronuncia- is accepted. It is generally agreed that the term is ed from "keramos," the Greek word for potters' earth r articles made from burnt clay, or even through the k keramos to a Sanscrit word meaning "to burn." ever, another school of thought considers it was derived the word Kerameicus which was that quarter in the -west side of ancient Athens. The inhabitants of the ity, i.e. Kerameis, exercised the trade of potters; the meis also sacrificed to their god Keramus. There is an bstantiated story which relates how the gods were singled or different trades and professions, for example Diana unters and Neptune for sailors. Towards the end of the ibution there were only two gods left for allocation, ely Keramus and the Devil, and the only two trades left ovided for were the potter and the lawyer. Neither ed the devil. In order that the allocation might be fair, otter and the lawyer were blindfolded and placed in a room with the two remaining gods. It was there that otter received Keramus as his tutelary deity.(1)

ence potters are called "ceramists," and the potters' art eramic art and by an easy transition the term was very extended to all types of clay workers. General usage e can decide the meaning of a particular term, and it s to be accepted nowadays that the ceramic industries race the manufacture of a wide range of products, ugh at first sight some of them seem to have little in mon with the derivation of the word ceramics. For nce, clay products including building materials and ery, the many types of refractories and the range of sives might represent one end of the list, with glasses enamels at the other. Cements, chalk and salt products also be considered ceramics and, of course, the specialized mics now being developed for the nuclear reactor and lar modern industries are assuming increasing importance. evident from consideration of this array of products that rical and magnetic ceramics are only a small section, ough an important and growing one, of a large family of allied materials with completely different applications and with widely varying methods of manufacture. The section we are concerned with is most closely associated with the clay products and refractories groups, in that high temperature firing is involved as one of the essential manufacturing operations. In fact electrical and magnetic ceramics fall within the closer definition of ceramic materials of B.S.S. 1598 which states that "Ceramic materials are inorganic materials which are prepared and converted into the final vitreous state, by the application of elevated temperatures, while substantially retaining their unfired shape."

PRODUCTION OF ELECTRICAL AND MAGNETIC CERAMICS

The production techniques used for electrical and magnetic ceramics are typical of the pottery industry, but no longer are artistic shapes and decorative colours of much interest. In their place are substituted precise dimensions and carefully controlled electrical and magnetic properties. The art of powder technology, of which the much publicized powder metallurgy is a section, is widely used together with the more traditional clay working techniques. In the production of typical electrical and magnetic ceramics there are usually four main manufacturing sections, powder preparation, fabrication, firing and finishing. The body preparation, involving the composition, establishes the type of ceramic. There are a variety of alternative techniques for fabricating shapes—slip casting, jollying, turning, throwing, pressing and extrusion—but it is not usually possible to use all of these alternatives for each ceramic body owing to the peculiarities of each case. On the other hand, the relatively simple statement "firing" can prove to be a most complex operation with some of the new ceramics owing to the high temperatures, exact firing schedules and special atmospheres required. With regard to the finishing operations, undoubtedly the greatest difficulty in electrical and magnetic ceramic production is to control physical dimensions while maintaining requisite electrical or magnetic characteristics. A shrinkage of between 10 and 35% can take place on firing, depending on the type of ceramic, and this leads to distortion, etc., making dimensional control difficult. As ceramics in the fired or vitrified form are very hard, expensive finishing techniques, such as grinding, are usually necessary if precision dimensions of the order of one or two thousandths of an inch total tolerance are required.

Based on a lecture given before the Scottish Branch of The tute of Physics on 1 February, 1957.

PROPERTIES OF ELECTRICAL AND MAGNETIC CERAMICS

When considering the field of electrical and magnetic ceramics, it is an interesting exercise to try to collect the various types into broad groups, and one such classification comprising insulator and conductor, ferroelectric and ferromagnetic ceramics is shown in Table 1. Of course the grouping is not rigid or exclusive and some of the types appear in more than one group. Also, only typical ceramics have been allocated to each application and it is recognized that many others could be included.

The functions of insulator and conductor ceramics are readily appreciated although the theoretical aspects are complex, involving ionic conductivity, crystal imperfections, lattice mobility, energy levels and band structure and, of course, the semi-conductor aspect is now a whole branch of technology on its own account. However, it is of interest to indicate briefly some of the underlying theory. The insulating properties of the majority of ceramics and inorganic compounds arise from the firm bonding of the electrons to the component atoms so that considerable energy is necessary to promote them into the conduction band. The energy gap between the valency level and the conduction band is rendered less effective by increasing temperature so that all insulating bodies show an exponential fall in resistivity as the temperature rises. The electrons attached to almost any impurity ion present in a crystal lattice will have a higher energy than those attached to the major constituents; there will thus be a lower energy gap and therefore a lower resistivity. In consequence, high purity alumina is found to be an order better as an insulator than material of normal commercial purity. Electrons in higher energy states will also be present on surfaces and at lattice imperfections so that a single crystal of a good insulator will have a higher resistivity than the ceramic form of the same material. Thus sapphire (single crystal alumina) is a further order higher in resistivity than the pure polycrystalline ceramic form.

The so-called donor impurity may be an excess of one of the major constituents. Zinc oxide, for instance, may contain a sufficient excess of zinc atoms to cause it to have a distinct red colour and resistivity down to $10^{-2}\ \Omega$ cm. There is also a mechanism, where ions of variable valency are present, which does not involve the presence of ions in the conduction band. If two ions of the same element, differing by unity in valency, are present on neighbouring, similar, lattice sites, electrons can pass from one to the other with very little energy change. This process occurs in magnetite, Fe_3O_4, giving resistivities down to $10^{-2}\ \Omega$ cm, and is also the cause of the small degree of conductivity present in the magnetic ferrites.

Passing on now to the ferromagnetic and ferroelectric classes of ceramics, the functions and properties here are less widely appreciated. The ferromagnetic ceramics have characteristics which can be described by the same parameters as those of metallic magnetic materials, although strictly the causes of their magnetic properties differ to some extent and ferromagnetic ceramics or ferrites have been shown to be, in fact, anti-ferromagnetic. These ceramics are developments arising from the magnetic properties of the minerals magnetite (i.e. ferrous ferrite Fe_3O_4) and magnetoplumbite ($PbFe_{12}O_{19}$). The former class of ferrites is magnetically soft and materials which are of practical importance consist of two or more of the single ferrites of nickel, zinc, manganese, magnesium, copper, etc., which crystallize in the cubic system in the same class as the mineral spinel ($MgAl_2O_4$). The principal virtue of soft ferrites relative to other magnetic materials, is their high resistivity which results in low eddy-current losses from audio-frequencies up to the centimetric waveban
Also a high initial permeability and low hysteresis loss can achieved by contriving to obtain a stress-free cubic struct and minimum magnetostrictive properties.

Table 1. *Electrical and magnetic ceramics*

Class	*Application*	*Types*
Insulator	Low frequency	Porcelain
	High frequency	Steatite: cordierite: corun dum
	Low permittivity dielectric	Titania: magnesium titanate, strontium
		Titanate: calcium titana
Ferro-electric	High permittivity dielectric	Barium titanate: bariu titanate–stannate
	Piezoelectric	Barium titanate: lead zi conate–titanate, lead metaniobate
Ferro-magnetic	Magnetostrictive	Nickel zinc ferrite
	Low frequency	Manganese zinc ferrite
	High frequency	Nickel zinc ferrite
	Very high frequency	Cobalt barium ferrite
		Magnesium manganese ferrite
	Permanent magnet	Cobalt ferrite: barium ferrite
Conductor	Low resistivity	Silicon carbide: Magne
		Metal oxides
	High resistivity	Zinc nickel oxide
	Semi-conductor	Metal oxides and carb

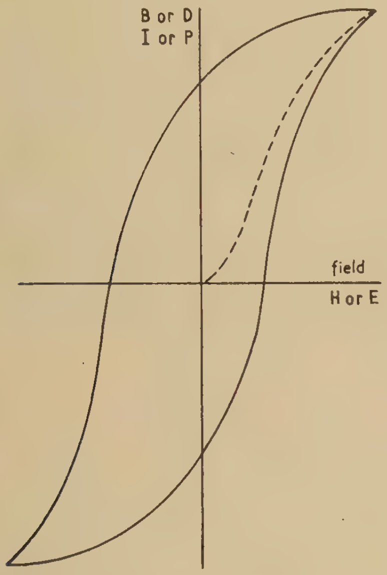
The second class have permanent magnet properties a the materials of practical importance here are cobalt fer and barium ferrite ($BaFe_{12}O_{19}$) which crystallizes in hexagonal system. Hard ferrites owe their peculiar perman magnet properties of extremely high coercive force and l permeability to the large anisotropy of their hexagonal crys structure and also to the fact that in manufacture a clo approach can be made to the critical particle size (i.e. a sing domain) for optimum value.

Ferroelectric ceramics, on the other hand, are based barium titanate ($BaTiO_3$) which, above the Curie poi crystallizes in the cubic system similar to the mineral perov skite. Below this temperature the structure deforms slight into a tetragonal unit cell and this is the form stable at roo temperature. Materials of practical importance are titanat of barium, often mixed with those of strontium, magnesiu calcium or lead, etc. Zirconates, stannates, niobates an other mixed oxides are also of importance in this grou With regard to titanates, their chief asset is their high pe mittivity up to several thousands at useful engineeri frequencies and normal operating temperatures. In additio the fact that polycrystalline barium titanate, which is normall electrostrictive, retains a large polarization after the ten porary application of a high electric stress, renders it effectivel piezoelectric and so makes feasible its use as a transduc material.

Ferroelectricity is the dielectric analogue of ferromagneti and ferroelectric ceramics are so called because of their ver close analogy to the ferromagnetic ceramics—not because any relationship to iron. It is appropriate at this stage compare the two classes of materials noting the analogies an the differences. The similarity of the ferromagnetic and ferr electric parameters is apparent from Table 2 and this make

2. *Ferroelectric and ferromagnetic ceramic parameters*

Ferromagnetic		*Ferroelectric*	
etic field	H	Electric field	E
etic induction	B	Displacement	D
etization	I	Polarization	P
tibility	k	Dielectric susceptibility	k
ability	μ	Permittivity	ϵ
ive force	H_c	Coercive field	E_c
etostatic potential etomotive force	$\int Hdl$	Electrostatic potential	V
		Electromotive force	e.m.f.
etic flux	ϕ	Charge	Q
tance	L	Capacitance	C
sible magneto-tive constant	λ	Piezoelectric strain constant	d
		Piezoelectric stress constant	g
temperature	θ_c	Curie temperature	θ_c



teresting study. This comparison can also be extended clude electrical and magnetic losses. For example, in cases the area of the hysteresis loop gives the hysteresis er cycle of applied alternating field; for a given field itude, therefore, hysteresis loss in each case is pro- onal to frequency. Conduction in a magnetic material to eddy-current losses, which increase as the square of ency, since induced voltages increase with frequency for d flux density. In the dielectric case, on the other hand, uction or leakage introduces a corresponding type of but since the voltage associated with a given field or ization is independent of frequency, the loss does not with frequency. The impedance of a capacitative onent, however, decreases with increase of frequency that of an inductor increases. Consequently the con- tion of eddy and leakage currents to power factor, i.e. impedance/reactive impedance, increases in the inductive and decreases in the capacitative case. In addition to the known hysteresis and conductive losses, a ferrite possesses ctric losses associated with its permittivity, whereas ctrics usually have no magnetic properties and the con- case does not apply. The residual losses of a magnetic rial, which are still not fully understood and which include temperature-dependent and time-dependent components, have their counterparts in dielectric relaxation, absorption and significant variation of power factor with temperature.

Of course magnetostrictive effects in a ferromagnetic and their associated losses have their counterpart in the piezoelectricity and electrostriction exhibited by ferroelectrics.

The analogies between ferromagnetism (or anti-ferromagnetism) and ferroelectricity are extensions of the well-known analogies between paramagnetic and dielectric behaviour where magnetic and electric fields, magnetic and dielectric polarization, etc., are comparable in many aspects.

In ferromagnetic and ferroelectric materials a spontaneous polarization to saturation, even in the absence of an externally applied field, sets in below a certain critical temperature called, in both cases, the Curie temperature. In ferromagnetic materials this is due to interaction forces between neighbouring spinning electrons, producing nearly parallel alinements of the spins, and this is the basic reason for magnetization of ferromagnetic materials. In unmagnetized ferromagnetic materials the stable domain structure is random and such as to minimize the total free energy below this Curie temperature (otherwise free poles would exist at the extremity of all magnetic bodies). A similar minimizing of the free energy and therefore a domain structure exists in ferroelectric materials. The types of domain structure for the two materials are very different because certain terms in the free energy expression are of different orders of magnitude. The primary difference is in the "strictive" terms. It is generally accepted in the case of ferroelectric barium titanate that the high permittivity results from the high degree of induced polarization which occurs in the crystal due particularly to the motion of the highly charged titanium ion, although other theories exist to explain the effect. In barium titanate the crystal axes parallel to the polarization direction and that perpendicular to it differ in length by 1%; therefore a 90° domain rotation can represent a 1% change in dimensions. For ferromagnetic materials the corresponding change in dimensions is of the order of 0·001%. These effects mean that a much larger energy is required to produce a comparable change in state for a ferroelectric material than for a ferromagnetic one. In particular, the coercivities and hysteresis loop areas are greater for the ferroelectrics.

Another major difference from a theoretical aspect is in the type of transition occurring at the Curie temperature. Ferromagnetic materials (except in a few isolated cases), undergo a second order transition at the Curie temperature, whereas a ferroelectric body undergoes a first order change with appreciable discontinuous changes in lattice constant, etc.

APPLICATIONS

Turning now to the practical applications of electrical and magnetic ceramics, it might be appropriate to look at the subject from the user's point of view. It is evident from the description "electrical and magnetic ceramics" that one of the major outlets for these materials will be in the field of electrical and electronic engineering, but the wide range of applications now covered is not generally realized. When any circuit diagram is examined, it is surprising how often these ceramic materials are used either as components or part of a component and, more important, how many new devices are being developed around certain specialized properties.

To give some idea of the influence of this family of materials in electronic and electrical engineering, broad component groups have been set out in Table 3 and the appropriate ceramics indicated. Reference to all the applications listed is not possible and only a few of the barium titanate and soft and hard ferrite application developments will be dealt with.

Table 3. *Some components using electrical and magnetic ceramics*

Description	*Types of ceramics*	*Typical applications*
Insulators	Porcelain	Low frequency insulation
	Steatite	High frequency insulation
	Cordierites	Dimensional stability
	Corundum	High temperature insulation
Conductors	Metal oxide glazes	Conductive coatings
Resistors	Metal oxides	Thermistors
	Semi-conductor oxides	Varistors
	Semi-conductor carbides	Furnace elements
Capacitors	Rutile (titania)	Low permittivity
	Titanates	High permittivity
	Stannates Niobates	High temperature
Inductances	Ferrites	Transformer cores
		Memory cores
	Steatites	Coil formers
Amplifiers	Titanates	Dielectric amplifiers
	Ferrites	Magnetic amplifiers
	Rare earth ceramics	Valve cathodes
Transducers	Ferrites	Magnetostrictive
	Titanates	Piezoelectric
Switches	Ferrites	Transfluxors
	Steatite	Insulators
Microwave components	Conductive oxides	Dummy loads
	Ferrites	Gyrator elements
	Titanates	Radar lenses
Permanent magnets	Ferrites	Magnetic lenses

FERROELECTRICS BASED ON BARIUM TITANATE

Ceramic capacitors. Barium titanate high permittivity types of capacitors are well known in the familiar disk, rectangle and tube form giving values from about 500 to 30 000 pF and with d.c. working voltages in the region from 300 to 1000 V. Most engineers are probably familiar with the shape of the curve, showing the variation of dielectric constant with temperature for barium titanate, which rises to a maximum of about 10 000 at 120° C. The development by ceramic capacitor manufacturers of alternative compositions having barium titanate as a major component with other titanates, such as strontium and calcium, etc., has had as one of its main objectives the modification of this curve shape for different applications.

Fig. 1 shows the three curves which represent broadly the main types of ceramic capacitor on the market at present. Obviously any development which could raise the permittivity but still maintain a flat temperature coefficient would be highly desirable. To give the whole story, these curves should be plotted for different voltages as the "peaky" curves are usually associated with high voltage coefficients. Lastly, the power factor/temperature characteristics must not be neglected and usually values of about 1% are achievable at normal operating temperatures and engineering frequencies.

Two further aspects concerning ceramic capacitor manufacturers are miniaturization and high temperature performance. Miniaturization frequently goes with low voltage operation and so the ceramic dielectric can be made thin. Capacitors from ceramic film a few thousandths of an inch thick have been made and a representative range is shown to Fig. 2. The single layer units range in value from 1000 to 10 000 pF and will operate about 250 V a.c. or 350 V d.c. and have a breakdown voltage around 1000. Also in Fig 2 are shown higher capacity units—which can be made up values up to 1 μF, obtained by interleaving the ceramic dielectric layers and making them into a pack. Two methods can be used here, the first is to fire the ceramic sheets, silver and slit to size, and then stack. The other is to apply

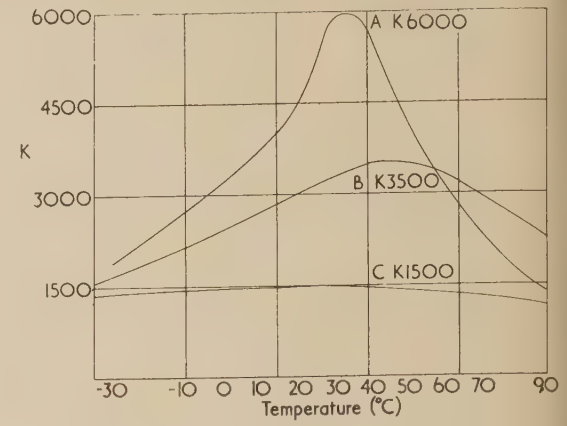


Fig. 1. High permittivity ceramic capacitors; permittivity/temperature characteristics

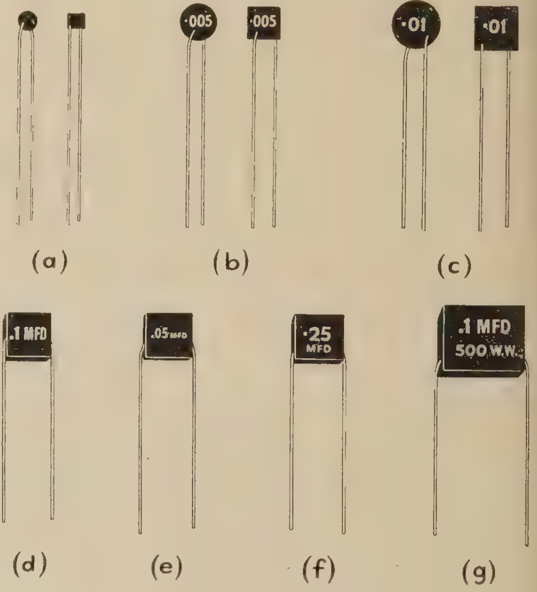


Fig. 2. Ceramic film capacitors

	Capacity (μ*F*)	*Working voltage* (*V*)	*Proof voltage* (*V*)
(*a*)	0·001	250	800
(*b*)	0·005	250	800
(*c*)	0·01	250	800
(*d*)	0·1	250	500
(*e*)	0·05	250	500
(*f*)	0·25	250	500
(*g*)	0·1	500	1000

ium electrodes to the unfired sheet and fire; this gives ller pack but is a more expensive method.

rk is now going on to replace the expensive precious electrodes by a base metal which means firing in a ng atmosphere which barium titanate ceramics do ce.

h regard to high temperature performance, reference to shows that as the operating temperature of a capacitor sed, the capacitance generally falls, especially above

some applications, particularly at low frequencies, the constant *CR* of the capacitors is important. Since the ge resistance is dependent on both temperature and e for materials of this type, it is usually very difficult intain a constant, or even a high *C–R* product over e temperature range. It has proved possible, however, these ceramic "film" type capacitors to obtain 0·1 to F units with insulation resistance of over 200 MΩ at C with 350 V d.c. applied. Suitable protective coatings e this performance to be maintained even after exposure vere humidity conditions. It is anticipated that the on of new components such as cerium oxide will result extension of these useful properties up to 150° C.

zoelectric transducers. Since barium titanate is ferro- ic and has quite an appreciable coercive field of the of 7000 V/cm, it can be polarized to a remanent state ich it will substantially remain for an indefinite period hus display piezoelectric properties. When in this state is an almost linear relationship between electric field echanical strain and also conversely, between mechanical and electric charge—thus giving transducer possibilities. characteristics of a barium titanate material which has developed for high power can be seen in the curves and s of Fig. 3.

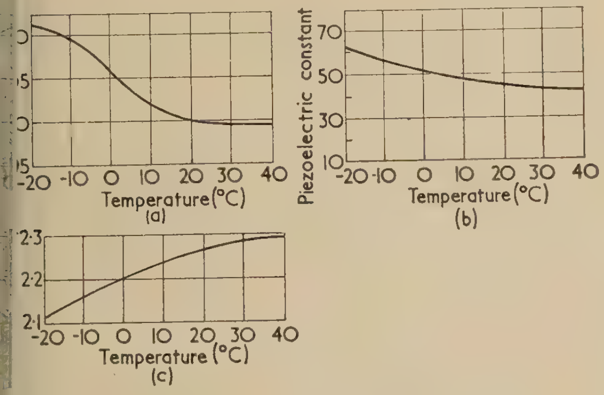


Fig. 3. Nominal characteristics of piezoelectric barium titanate

) Dielectric properties at 20° C.
Relative dielectric constant, 1000.
Loss tangent: not greater than 0·025 at 10 kc/s, 2·5 kV/cm;
d 0·015 at 1 kc/s, low field.
Resistivity, 3 × 10^{12} Ω cm.
) Piezoelectric constants.
Longitudinal thickness: mode d_{33}, 8·3 × 10^{-6} cm/kV.
Longitudinal length: mode d_{31}, 3·5 × 10^{-6} cm/kV.
Electromechanical coupling: factor (length mode) k_{31}, 16%.
) Physical properties.
Density: 5·7 g/cm³.
Compliance: S_{11}^{E} 0·94 × 10^{-12} cm²/dyn.
Temperature coefficients: permittivity −0·2% per ° C;
equency constant +0·15% per ° C.
Breakdown strength: 30 kV/cm.

The notable features here, apart from the piezoelectric constants, are the low P.F. (about 2½% at 10 kc/s and 2·5 kV/cm of a.c.) and a low enough temperature coefficient of frequency constant so that an element remains reasonably well in tune to the frequency of a driving source when quite high intensities of power are fed into the ceramic.

One other factor which must be taken into account is the change of properties with time due to slight relaxations which take place in the polarization of the material on shelf storage. This is referred to as ageing. The piezoelectric sensitivity decreases, the capacity decreases, and the resonant frequency of a resonator increases logarithmically with time. Usually the first twenty-four hours account for a 10% change, the next 10% change takes about one month and the next 10% some years, so after a month or two the performance is stable enough for most purposes.

The material can be provided in the form of disks, tubes, rings and plates. Large samples have been made in disk, slab and ring form up to a maximum of 6½ in. diameter × ¾ in. thick, 7 × 7 × ½ in., 4½ in. diameter × 3 in. high respectively.

Some applications for the material are shown in Table 4. Ceramic pick-up elements of the "bender" type are rapidly replacing Rochelle salt in crystal pick-ups for gramophones. The sensitivity of barium titanate is about half that of Rochelle salt. Barium titanate offers advantages, however, where high temperature or humid conditions are expected, since it is quite stable up to 70° C and is not permanently affected as is Rochelle salt, by high relative humidities.

Table 4. *Applications of piezoelectric barium titanate*

Underwater sound	Sonar systems	Echo ranging systems
	Sound detection	Sound emitters
	Sound measurement	Fathometers
Ultrasonics	Non-destructive materials testing	
	Rapid cleaning of machined parts	
	Drilling, cutting, of hard materials	
Medicine	Vaccine extraction	Therapy
	Sterilization	Brain surgery
	Diagnostic work	
Shock and vibration	Accelerometers	Displacement gauges
	Pressure and blast gauges	Strain gauges
General	Gramophone pick-ups	
	Filters and oscillators	
	Surface gauges	

Although barium titanate can usefully replace quartz as a generator of high power ultrasonic vibrations with the advantage of a lower input impedance, it is unlikely, for some time at least, to replace quartz in its use for frequency standards, owing to the relatively high temperature coefficients and ageing factors.

Dielectric amplifiers. Barium titanate-based ceramics with additions of tin having relatively low loss and hysteresis loops showing a rapid change of permittivity with biasing field, can be used in dielectric amplifiers circuits. This change in permittivity can be used to throw an initially balanced bridge, containing the capacitor in one arm, out of balance, thus constituting a power gain for the circuit of up to 10 000.

Alternatively, it can be used to change the frequency of a resonant circuit.

Disks of ceramic as manufactured for this use are usually approximately 1 cm in diameter and 0·15 cm thick. Evaporated silver electrodes are used of such a size that the a.c. capacity at 200 V (15 kV/cm) is of the order of 500 pF. Several electrodes evaporated on each disk give a set of capacitors having identical characteristics.

For fields between 0 and 3 Vk/cm the permittivity will diminish by at least 1% for an increase in filed of 0·1 kV/cm. One snag of the material as developed at the moment is that the permittivity maximum of the material is around room temperature and hence the capacitor has a large temperature coefficient of capacity, the capacity falling to half its value for a temperature rise of 15° C.

Memory devices. A new and important application for barium titanate is in memory devices. Single crystals of pure barium titanate which strictly speaking, of course, are not ceramics, can be grown in the form of thin right-angled triangular plates from a flux of potassium fluoride. They vary in size but have an average hypotenuse of 1 cm and an average thickness of 0·1 mm, also they can be etched down to any required thickness using phosphoric acid. After treatment to orientate the crystal axes with respect to the faces, electrode bars can be evaporated on to the surface. These bars are mutually parallel on one face and normal to the bars on the other face. Fig. 4 shows a typical 1 × 1 single cell unit formed in this way; 3 × 3 (9 cells) units are mounted on B9G valve bases and used for experimental work, and 10 × 10 (100 cells) units are considered as a reasonable size for use in a computer. Such units are extremely compact. Crystals so treated have very square hysteresis loops (displacement/field curves) as shown in Fig. 5. This curve compares in every way with the more familiar square hysteresis loop curves of certain ferrites which will be described later. Here the peak applied voltage is 56 V at 50 c/s. The squareness ratio Rs of the loop is defined as the polarization at half the peak depolarizing field divided by the maximum polarization, i.e. $P(-E/2)/P(+E)$. The squareness ratio can be as

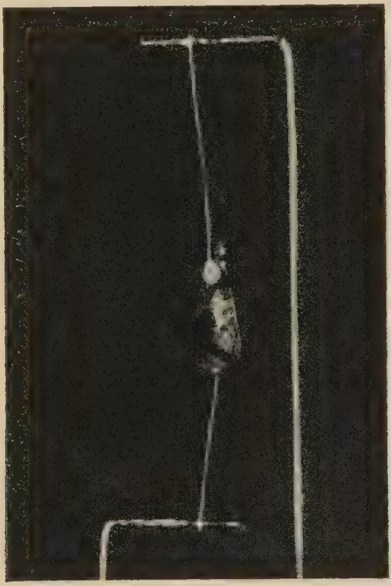


Fig. 4. 1 × 1 memory unit evaporated on to a typical barium titanate single crystal

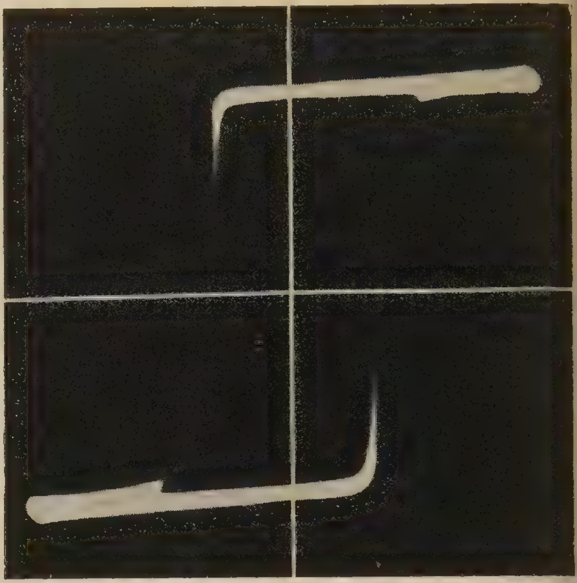


Fig. 5. Hysteresis loop (D/E) peak applied voltage 56 V 50 c/s

Table 5. *Properties of different magnetic materials*

Name	*Permeability* *Initial*	*Permeability* *Maximum*	*Saturation flux density B(max) = μHmax gauss × 10³*	*Curie point*	*Electrical resistivity (μΩ.cm)*	*Normal frequency range*	*Normal working permeabilities*
Silicon iron	500	7 000	19·7	690	60	$0{\cdot}2 \times 10^6$ c/s	400–5000 at 50 c/s
Grain orientated, FeSi	1 500	40 000	20	740	47	$0{\cdot}2 \times 10^4$ c/s	1500–15 000 at 50 c/s
Radio metal	2 000	20 000	15·6	500	55	$0{\cdot}2 \times 10^4$ c/s	1500–7000 at 50 c/s
Mumetal	20 000	100 000	6·5	600	62	$0{\cdot}2 \times 10^4$ c/s	8000–20 000 at 50 c/s
Flake iron	250	950	15·5	—	10^4	50 c/s–50 kc/s	500 at 10 kc/s
Pressed carbonyl iron powder 40% air and filler	20	—	15	—	10^{10}	1–45 Mc/s	5–10 at 2 Mc/s
Ferrite (1), MnZn	800	14 000	3·2	130	5×10^{10}	10–100 kc/s	800 at 10 kc/s
Ferrite (2), low frequency NiZn	125	450	3·3	380	10^{13}	100 kc/s–10 Mc/s	125 at 1 Mc/s
Ferrite (3), high-frequency NiZn	850	5 000	3·5	150	10^{11}	10–50 kc/s	3000 at 10 kc/s
Ferrite (4), MnNiZn	20	45	1·5	300	10^{12}	10–100 Mc/s	20 at 50 Mc/s

s 96–97% and in this case is, in fact, 97%. As a result, atios of switched signal to non-switched signal can be ied. For instance, for 30 V input, the ratio is 50 to 1. h a material can be used as a binary store in a computer, ccess times of 10 μs. Because of the small volume of ements (they can be as small as 10^{-3} mm^3) the power mption can be many times less than for standard in. diameter ferrite cores.

ROMAGNETICS BASED ON SOFT FERRITES(2)

re are several types of soft ferrite—the common ones manganese zinc ferrite and nickel zinc ferrite—having nt magnetic characteristics which are compared in the part of Table 5 with the more conventional materials . In manufacture, emphasis can be given to one or of these properties, chiefly permeability, saturation and cal resistivity and losses. The materials usually appear market as a series of grades for particular applications. es compare unfavourably with laminations in saturation ensity, which so far has limited their use at power ncies and high flux densities. However, in the U.S.A. nese zinc ferrites are now commercially available with tion flux densities of about 4500, and manganese zinc s have also been produced in the laboratory with tion flux densities of 5500. With increase in frequency, s become more favourable owing to the fact that the vities of the irons are around 40 μΩ cm, while that of ferrites is 10 MΩ per cm^3 and above about 10 kc/s have few competitors as core materials.

e bulk of the soft ferrite production is for radio and sion components together with the telecommunications try. Roughly 300 tons per year are required in the d Kingdom.

evision receiver components. Some typical television er components are shown in Table 6, with the dominant rial parameters indicated for each item. The ferrites usually nickel zinc or managanese zinc types. Most cists and engineers will be familiar, in a broad sense at with the components and it is not necessary to go into .

Table 6. *Television components*

Component	*Dominant parameter of ferrite*
anning coils	Permeability, mechanical accuracy
H.T. transformers	Flux handling capacity
idth controls	Permeability
nearity controls	Saturation characteristic
ocking oscillator transformers	Permeability, resistivity
As permanent magnets	
ocus units	Coercivity
n trap units	Coercivity, cost
ntring units	Coercivity, cost
cture shape correctors	Coercivity, resistivity

dio components. Perhaps the best known and most lar application of ferrites in the pure radio field (as ct from television) is in the rod aerials which have been oped in the past three years for use in portable receivers eplacement for the larger frame aerials. Fig. 6 illustrates rinciple of operation of an aerial rod. The grades of e used for the long, medium and short waves are usually l zinc ferrites, sometimes with additions of other components. Recently a method has been found of using high permeability ferrites designed for lower frequency operation by extruding rods with slots which effectively reduce eddy-current losses.

Ferrites can also be used for most types of filters, R.F. coils and I.F. transformers and offer increased permeability and reduced losses over other core materials. It is probable that the advantages of diminished size together with comparable or superior performance will assume increased importance for miniaturization as printed circuit and transistor techniques are more widely adopted.

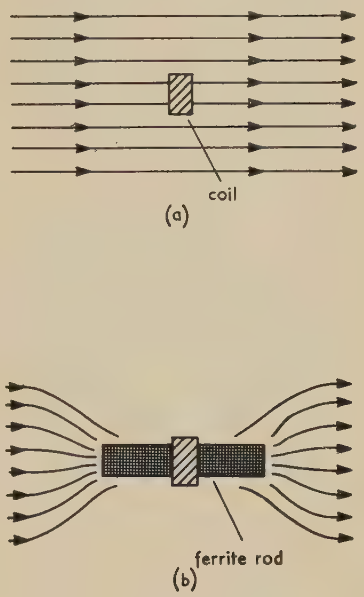


Fig. 6. Principle of operation of an aerial rod

(*a*) Coil in a uniform magnetic field linked by two lines of flux.

(*b*) The introduction of a ferrite rod distorting the uniform field and increasing the flux linkage of the coil.

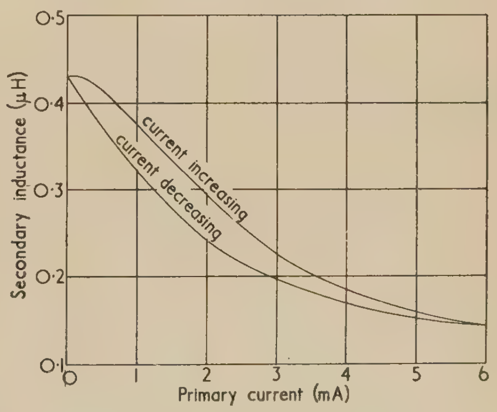


Fig. 7. Typical inductance *versus* current graph for a magnetic reactor unit

Frequency of measurement, 45 Mc/s; primary winding, 2000 turns; secondary winding, 5 turns.

A very interesting characteristic of certain ferrites is the change of permeability that a polarizing field can effect. Fig. 7 gives an indication of the scale with which variation of a polarizing field can control the effective inductance of a secondary winding. This method of control provides obvious possibilities for general permeability tuning, but problems of circuit alinement, hysteresis and temperature effects make this a complex matter. Fig. 8 gives details of a successful component using this principle for tuning and modulation on the range between 29 and 60 Mc/s. Here variations of a d.c. level of primary current are used to change the mean value of a secondary coil inductance. This is used to set nominal operating frequency and to stabilize the oscillator for circuit changes, while a further superimposed a.c. is applied for frequency modulation by speech signals. There are a number of interesting subsidiary characteristics of this component, some of which are indicated on Fig. 8.

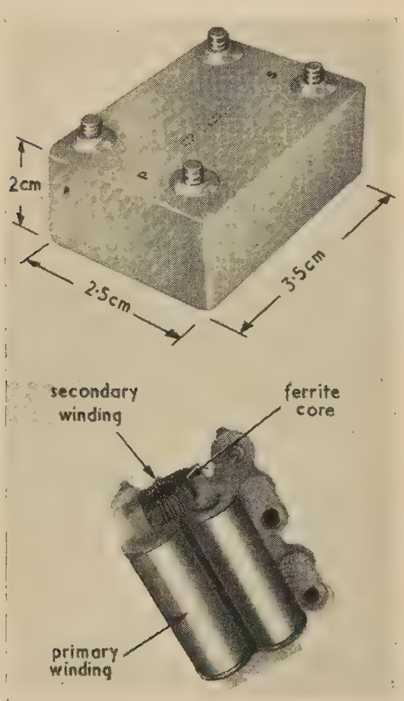


Fig. 8. Magnetic reactor

Mean secondary inductance, 0·25 μH; static slope of secondary, 0·02 μH/mA change of primary current; primary inductance, 2 H; secondary Q, 10 at 45 Mc/s; temperature coefficient of secondary inductance, 5 × 10^{-4} parts per ° C between 20 and 90° C.

Very high-frequency applications. Manganese magnesium ferrites, together with some nickel zinc ferrites, give good properties in the very high-frequency and ultra high-frequency bands due to their reasonably high permeabilities in the region 10 to 50, and low losses. Some new "soft" hexagonal ferrites have recently been described and they rightly come in this section also.

The upper frequency limit of operation of a ferrite is not governed by the resistivity of the material, as is a laminated metallic magnetic core material, but by another mechanism associated with the magnetic anisotropy of the material. All the soft magnetic materials developed before these new hexagonal ferrites were cubic in crystal structure (spinel), and for these materials the product of the initial permeability and the upper frequency limit was approximately constant (this constant depending upon the cubic structure and associated anisotropy). As a consequence of this effect, in order to use a ferrite at high frequencies, a sacrifice in initial permeability had to be made. For permeabilities of about ten the upp frequency limit is of the order of 50 Mc/s for the spin ferrites.

The new compositions are hexagonal in crystal structu somewhat similar to the barium ferrite materials, but the easy direction of magnetization is in the basal plane of th hexagon. For such materials the initial permeability-upp frequency limit constant is much greater and material can b made with permeabilities of ten to frequencies above 500 Mc/ A typical composition in this group of materials $3BaO . 2CuO . 12Fe_2O_3$.

This increase of a factor of ten in upper frequency lim is a major step in magnetic materials development and ope up a whole new range of possible applications and promis to extend the useful range of ferrites in aerials and other typ of tuned circuit well up into the very high-frequency regio

Magnetostrictive transducers. Some of the ferrites, indicated above, exhibit magnetostrictive properties like oth magnetic materials. Often these are undesirable since th can be responsible for high hysteresis losses, and in so applications, such as television line-output transformers, audible whistle often produced can be most disconcertin The effect can, however, be turned to good effect in magnet strictive transducers and some grades of nickel ferrite ha been developed which can be used for a number of interestin applications. The magnetostrictive effect is a maximum the temperature at which the anisotropy coefficient is minimum and this temperature can be controlled by replac a small amount of nickel by cobalt. Bringing the maximu to room temperature enables coupling coefficients of 30% be obtained. Such material is suitable for hydrophones an medium power ultrasonic generators. Putting in rather le cobalt lowers the temperature of minimum anisotropy an enables the temperature coefficient of the elastic constants normal ambient temperatures to be controlled.

Fig. 9 shows plots of the relative values of the frequen constants of two ferrites, one containing only the coba normally present as an impurity in the nickel and the oth with 0·5% of the nickel replaced by cobalt. For the secon material the anisotropy minimum is shown by a correspondin minimum in frequency constant at −26° C, while for the fir this temperature is below the range used for measuremen The first material gives a negative temperature coefficient −50 parts per million per ° C and the second a positi coefficient of 35 parts per million/° C at room temperatur Very low coefficients are obtainable by adjusting the coba content. Materials which should be suitable for magnet

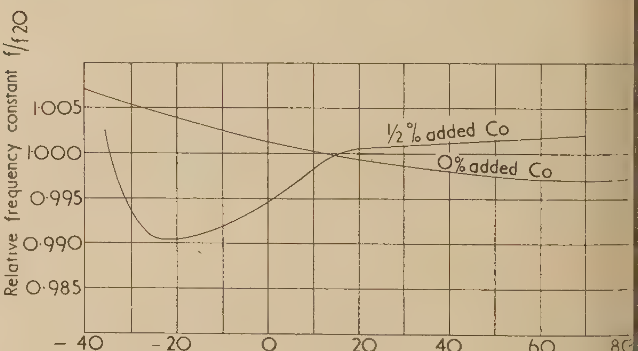


Fig. 9. Relative values of the frequency constant of two magnetostrictive ferrites

ctive filters and acoustic delay lines are therefore available. oupling coefficients are about 23%.)

Microwave components. In the past two to three years ny new developments have taken place around mixed rites of the manganese–magnesium family. Some ferrites, h compositions around $MgO_{(0\cdot2-0\cdot4)}MnO_{(0\cdot2-0\cdot4)}Fe_2O_{3(0\cdot4)}$, ibit rectangular hysteresis loops and are extensively used memory devices and switch applications which are dealt h below, and others, with compositions around $gO_{(0\cdot6)}MnO_{(0\cdot1)}Fe_2O_{3(0\cdot3)}$ exhibit low loss and useful meabilities up to very high frequencies. This latter composition can also be modified with advantage, by adding mina. The major application for this group of ferrites is microwave components and devices and sometimes nickel c ferrites are also used in this connexion. Great research ivity has taken place in this field and only the very broadest line of these applications can be given here.

Most of the uses of ferrites at microwave frequencies are sed on the Faraday effect which, as in the case of normal arized light passing through a magnetic field, produces a cession of the electron spins. This introduces a rotation the plane of polarization due to unequal refractive indices uencing the two circular components into which plane arized radiation can be resolved.

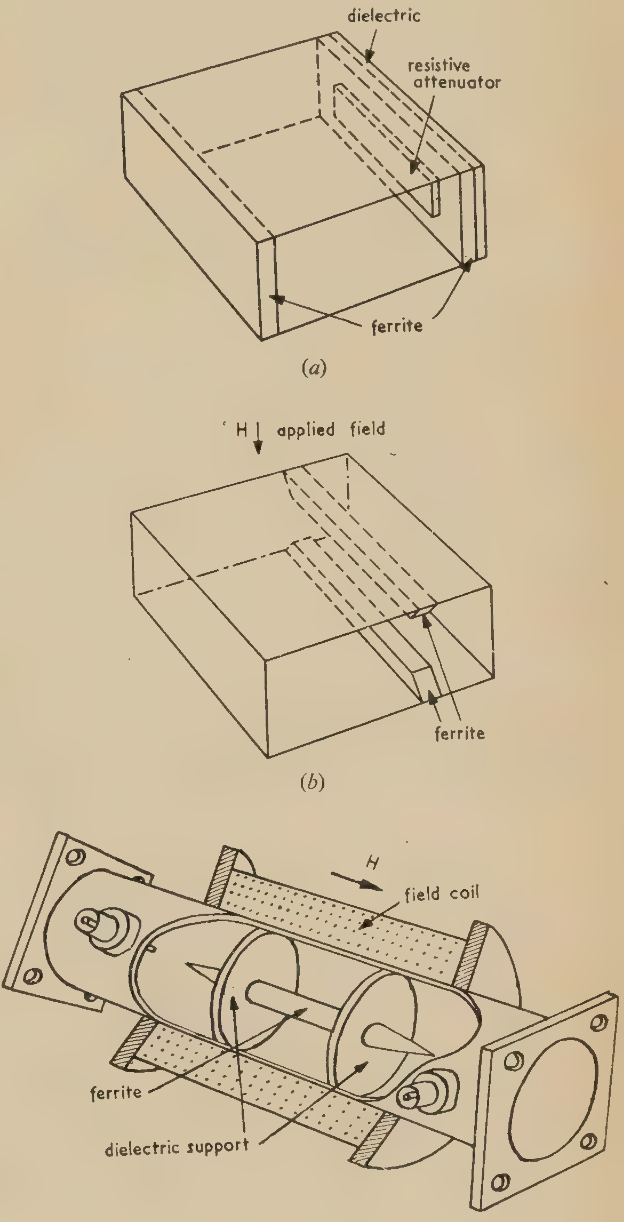
At certain frequencies and certain magnetizing field engths one or other of the component resonates and this ect is made use of in resonance type isolators.

t is possible, by the application or removal of the magnetic d, to change the transmission characteristics of a piece of tangular waveguide and also to make them different for two opposite directions of the propagation.

Typical instruments are illustrated in Fig. 10. Fig. 10(*a*) ows the use of two single strips of ferrite mounted on either e of a rectangular waveguide to provide a field displacement lator. Expressed in broad outline, the principle of operan is that the Faraday effect relating the vertical applied gnetic field and the circularly polarized components of the ctromagnetic waves in the ferrite cause one of the ferrite ps to exhibit a relatively high permeability and the other ow one to the incident energy. This has the effect of placing the electric field to one side of the guide, while a ve travelling in the opposite direction is displaced to the her side (we can imagine the two waves behaving like tor cars keeping to the rule of the road—both keeping to ir left-hand, or right-hand side). If a resistive card is now roduced on one side of the guide, this will absorb energy velling one way in preference to that proceeding the her way. The dielectric layer shown adjacent to one of the rite pieces has been found to lead to improved performance practice.

Fig. 10(*b*) illustrates a high-power type of resonance lator. This also shows a different permeability to energy velling one way along the guide from that met with by rgy travelling the other way. In one of these directions permeability, permittivity and Faraday effect cause ctromagnetic resonance to occur and energy is dissipated the ferrite. It has been found that the ferrite can either e the form of a thin vane across the height of the guide, two squat pieces against each broad wall as shown. The er arrangement gives good heat dissipation to the wall the guide and is therefore preferred for high power use.

Fig. 10(*c*) shows the more classical application (if a device y about four years old can be called classical) of the raday effect in a "gyrator" device. In this instrument the ne of polarization of a plane polarized wave in a circular veguide is rotated as the result of a longitudinal field reacting on the circular components into which plane polarized radiation can be resolved. The two oppositely circularly polarized waves are rotated at different rates and the net rotation is always in the same direction from whichever direction the incident wave arrives. If a wave is arranged to rotate 45° on passing once through a gyrator, and a reflected wave is rotated a further 45°, the reflected wave will reach the entrance to the gyrator rotated 90° relative to the incoming energy. It can then either be diverted through a separate channel, or absorbed in a vane, but will certainly not proceed down the input guide.



(*a*)

(*b*)

(*c*)

Fig. 10. Typical microwave components containing ferrites

(*a*) Medium power field displacement isolator.
(*b*) High-power resonance-type isolator.
(*c*) Four-part circulator.

Such a device can be used as a simple isolator or, as in the case illustrated, as a multi-port circulator, as a variable attenuator or switch or even as a modulator. The field can be provided by a permanent magnet, an electromagnet or by a coil system.

Ferrites have been used for other applications based on these and similar principles for tuning klystrons, in variable or fixed directional couplers, in aerial scanning devices and can, of course, be used at X-band, Q-band and also at S- and other less popular bands. A demand now exists at frequencies below S-band for Post Office microwave links.

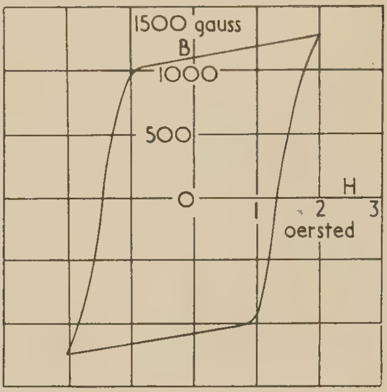


Fig. 11. Typical hysteresis loop of square loop ferrites

Memory devices. For memory devices the important ceramics are the rectangular loop ferrites, which are not restricted to the manganese magnesium family, although most of the grades at present available in production quantities are of this type. Much interesting work in recent years has resulted in the development of ferrites in which a rectangular loop can be induced by thermomagnetic treatment, i.e. cooli in a magnetic field (similar to the polarization of piezoelectr barium titanate).

With a material having a hysteresis loop with the chara teristics shown in Fig. 11, it will be observed that for maximum field of about 2 oersteds, the coercive force is abo 1·5 oersteds and that a demagnetizing field of 1 oersted wou only just bring the material to the knee of its hysteresis curv Such a material offers interesting possibilities for storage information. Consider a small ring of the material 0·080 i outer diameter and 0·050 in. inner diameter, the applicati of a current of about 800 mA amplitude in a single wi through the centre of the ring, or the simultaneous applicati of 400 mA pulses through two wires at the centre will ma netize the core momentarily to a flux density of about 1200 on the hysteresis loop, after which it will settle at the remane point. In this condition a core can be considered as holdi the binary digit "zero." The binary digit "one" can written into the core by the application of a similar curr pulse or pulses in the reverse direction, taking the core to t opposite corner of the loop corresponding to minus 1200 and finally to the other remanent point.

The information stored in such a core can be read o by applying a current pulse or pulses in the positive fie direction when a voltage pulse will be developed in a separa read-out wire linking the core if it held a "one," but only very small pulse will be produced if the core was storing "zero." Two systems are commonly in use for combining series of these cores into a complete memory and these a illustrated in Fig. 12. They are the direct selection syste [Fig. 12(*b*)] pioneered at Cambridge University and n preferred by several computer manufacturers in this countr and the coincident current system developed at the Mass chusetts Institute of Technology and widely used in Ameri [Fig. 12(*a*)]. In both systems a memory may be built co taining up to 10 000 words each of up to fifty binary digit

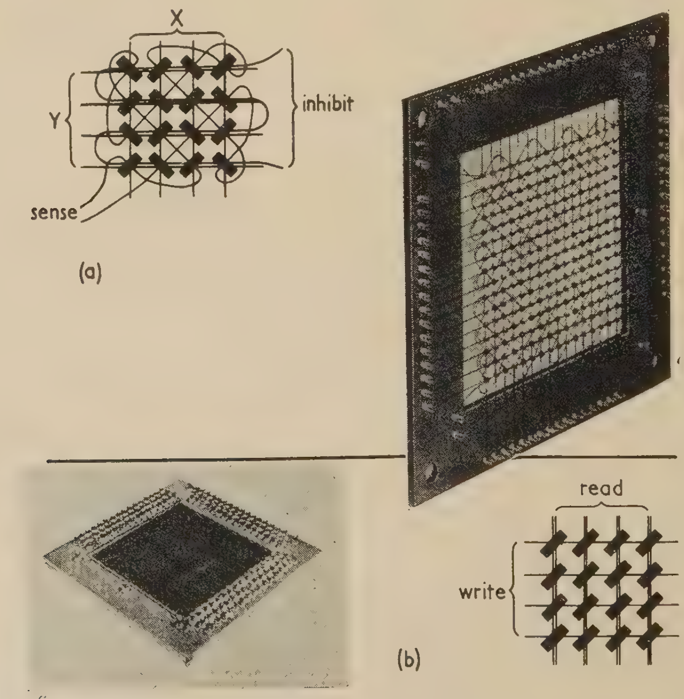


Fig. 12. Memory core planes: (*a*) American and (*b*) Cambridge systems

ch binary digit is represented by a ferrite core and thus some mories contain up to 500 000 cores. The design of mories and even of the matrices into which they can be divided is beyond the scope of this paper.

he use of transistors in computers makes it necessary to duce cores which will operate on currents of about mA peak. Grades of square loop ferrite are now available ich will operate on such low currents even in the 0·080 in. er diameter size, but these are generally too slow for most rs. Two other lines of approach are being actively pursued bring about lower operating currents without sacrificing ed. One of these is the manufacture of even smaller cores, h as 0·050 in. outer diameter, and the other is a new nique recently published which involves drilling 0·020 in. es in blocks of ferrite. Among other devices which have n developed around square loop cores are various types switches and logical elements.

ne of the more recent applications of square loop ferrites he transfluxor which is a ferrite disk with two or more es. This can be used for stores with non-destructive d-out, for pulse-operated switches whose setting will not disturbed by the signal switched, and many other possible lications.

ERROMAGNETICS BASED ON HARD MAGNETIC FERRITES(2)

ertain ferrites have useful and unusual properties as manent magnets and in Table 7 the remanence, coercive e and energy product characteristics of barium ferrite compared with more conventional magnet materials. ile the remanence is low the ferrite has a remarkably high rcivity and although the energy product is low, the density he material is about half that of metallic magnets. If the gy products are compared on a weight basis, the magnetic perties are much more equivalent. It also has a very low neability of approximately 1·2 and a high resistivity. to these properties, ferrite magnets can be used subtially without loss or demagnetization in the presence of fields. Applications in which these features are useful ude the small magnets used for picture shape correction, n centring units and ion trap magnets, and it is interesting note that the high coercivity solves serious practical culties in packing and shipment and subsequent use out magnetic change. Larger ring types with fields set pposition are used in focus units and Fig. 13 illustrates e of these applications.

Table 7. *Permanent magnet properties*

	Caslox Grade II (ferrite)	*Ticonal (G) nickel–iron anisotropic*	*Alnico II nickel–iron*	*Alcomax III nickel–iron anisotropic*	*Cobalt steel 35%*
BH_{max} (gauss oersteds)	$0{\cdot}8 \times 10^6$	$5{\cdot}7 \times 10^6$	$1{\cdot}7 \times 10^6$	5×10^6	$0{\cdot}95 \times 10^6$
Remanence (gauss)	2 200	13 500	7 250	12 500	9 000
Coercive force (oersteds)	1 600	580	560	670	250

his design of opposing magnet rings to provide a magc lens has been held responsible for astigmatism troubles some television receivers, and it is known that small gularities in the magnitude of the field on the axis of the ode-ray tube can cause this effect. Methods of appreciably icing astigmatism are now being applied with a resulting rovement in picture quality.

Several methods are being developed in this country and abroad for increasing the remanence obtainable in barium ferrite by orientation of the magnetic domains. These methods involve processing single domain particles of the material in the influence of magnetic fields and involve difficult production techniques. The increased flux density which can be achieved is, however, of considerable technical interest. B_{rem} values of 3500 G and energy products of $2{\cdot}5 \times 10^6$ G oersteds have been reported. When manufacturing problems associated with this process have been solved, the possibility of introducing this material into other permanent magnet devices, such as loudspeaker, d.c. motors and the like, will prove very attractive.

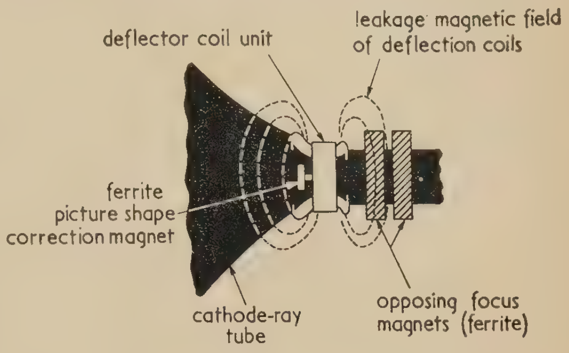

deflector coil unit
leakage magnetic field of deflection coils
ferrite picture shape correction magnet
cathode-ray tube
opposing focus magnets (ferrite)

Fig. 13. Ferrite magnet applications

FUTURE DEVELOPMENTS

And now, in closing, it is interesting to speculate how the wide range of electrical and magnetic ceramics currently available and in development will influence future design trends of electronic equipment and devices.

With ferrites for inductors, titanates for capacitors, insulators of steatite and alumina and resistors of conductive oxides or silicides, is it too much to expect that circuits of the future will consist of solid blocks of various ceramic materials, inert to moisture and capable of operating at relatively elevated temperatures?

In this same connexion, the penetration of the critical temperature barrier in the development of guided missiles and supersonic aircraft may require electronic equipment and devices to operate literally "red-hot" in order that electronic controls will withstand the heat generated by friction at extreme speeds. Ceramics and refractory metals will probably be the basis here.

If a transistor or rectifier could be made from a refractory substance one would expect to have a device capable of handling high powers at high temperatures. Transistor action has been demonstrated in very pure ceramics such as alumina, and titanium dioxide rectifiers have also been made.

However, satisfactory transistors and rectifiers will not be made from refractory substances until the immensely formidable problems of purity and crystal perfection are tackled and overcome. Perhaps the first successful device might be a power rectifier based on silicon carbide.

There is little doubt, however, that in the next decade or so electronic circuits based entirely on ceramics will be achieved.

ACKNOWLEDGEMENTS

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An optical probe for accurately measuring displacements of a reflecting surface

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The probe described is capable of accurately measuring the displacement of a plane reflecting surface along its normal without making mechanical contact with it. The image of an illuminated grating of special construction is formed on the surface to be observed, and the light reflected from this surface then forms an image of equal size on a second, exactly similar, grating. The disposition of the second image relative to the second grating depends upon the position of the probe relative to the plane surface and changes in this disposition cause variations in the amount of light transmitted which are detected photoelectrically. It is therefore possible to set the probe at a reproducible distance from ther eflecting surface by moving it until a predetermined level of light transmission is reached. Successive settings relative to a fixed surface indicate that the standard deviation of a single setting of the particular probe described is about $0{\cdot}4\,\mu$ ($1{\cdot}6 \times 10^{-5}$ in.). When the probe is used with a calibrated line standard, displacements may be measured with a standard deviation of $0{\cdot}7\,\mu$ ($2{\cdot}8 \times 10^{-5}$ in.).

1. INTRODUCTION

onnexion with the design of a new primary standard meter of long range at the N.P.L. it was necessary to se an optical instrument capable of measuring accurately changes in the level of the mercury surface within the meter tube by viewing the surface from above. Although optical probe described below was developed to meet e rather special requirements, it was realized that this instrument might have applications in other fields where e is a need to assess, precisely, displacements of a hanically inaccessible object which can be provided with a cting plane surface. The probe is described here as such nstrument. The barometer will be the subject of a later er.

2. PRINCIPLE OF THE PROBE

ig. 1 illustrates the fundamental principle of the optical e. The two projector tubes *AB* and *CD* are rigidly nected at an angle 2θ, each tube accommodating a grating ransmitting lines (*A*, *C*), normal to the plane of the paper. grating *A* is illuminated and the lens system at *B* forms a image on the plane mirror surface, situated at the apex he probe. The similar lens system at *D* produces at *C* a nd image of the grating *A* in the plane of an exactly lar grating, and the photocell P_1 provides a measure of the total quantity of light passing through this grating. It will be evident that the two gratings may be so adjusted in their holders that the image of the grating *A* coincides with the grating *C* when the reflecting plane of the mirror is exactly at the intersection of the optical axes of the two tubes. It is not essential that the image formed on the mirror surface should be of the same size as the gratings, provided that the image formed at *C* is of the correct size, but it is advantageous to use unit magnification throughout because the focusing arrangements are then the least critical and the following description relates to the probe working in this way. The function of the second photocell, P_2, is explained in section 4.

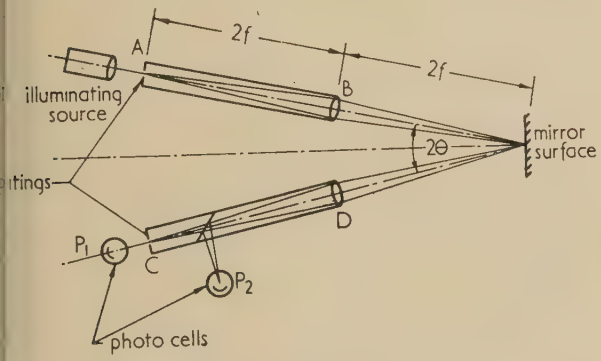


Fig. 1. Principle of optical probe

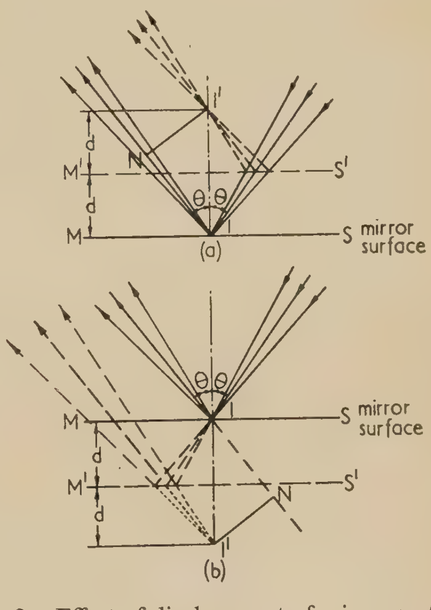


Fig. 2. Effect of displacement of mirror surface

Fig. 2 shows the effect of moving the mirror from *MS* to alternative positions *M′S′* at distances *d* from the apex of the probe. In Fig. 2(*a*) the image from grating *A* is now formed at *I′*, a distance *d* in front of the mirror; as seen along the axis of tube *CD* (Fig. 1) it therefore appears to have moved laterally a distance NI', equal to $2d \sin \theta$. A displacement of the mirror in the opposite sense, as in Fig. 2(*b*), has no effect on the position of image I, but as the only light from this image to reach grating C arrives by reflexion from the mirror, it appears to have come from an image at I', again laterally displaced a distance $2d \sin \theta$. The design of grating employed is such that when there is near-coincidence between grating C and the image of grating A a small relative displacement produces a considerable change in the quantity of light transmitted. Thus the new position of the mirror surface can be readily ascertained by moving the probe unit until a condition of coincidence is again indicated by the signal from the photocell.

3. THE GRATINGS

We have seen that the gratings must be designed so that a small relative displacement between the second or receiving grating C and the image of the first grating causes a measurable change in the amount of light transmitted. Further, when the two exactly coincide, the light transmitted must attain a sharp, outstanding maximum. The gratings used consist of 85 straight and parallel transparent lines 0·03 mm (0·0012 in.) wide formed on an opaque background, the centre line being separated from those adjacent to it by spaces of one line width, and successive spaces increasing in width progressively by 10% of a line width. The gratings are approximately 13 mm (0·5 in.) square and were reproduced photographically from a master grating made from a ruled aluminized glass plate. When two such identical gratings are in exact coincidence there is an uninterrupted path for the light through all the lines. For a small relative displacement in either direction there is a rapid decrease in the total light transmitted which reaches a minimum (nominally zero) for a displacement of one line width because all the lines of each grating are then opposite opaque spaces. Further displacement in the same direction produces a secondary maximum, followed by further less striking but characteristically disposed minima and maxima. The variation of the photocell current with relative displacement of the gratings is shown in Fig. 3. It should be noted that the greatest rate of change of photoce current with image displacement occurs between the maximu signal at coincidence and either of the two adjacent minim It follows, therefore,. that the highest precision of setting the probe can be achieved at a signal level about midwa between maximum and minimum.

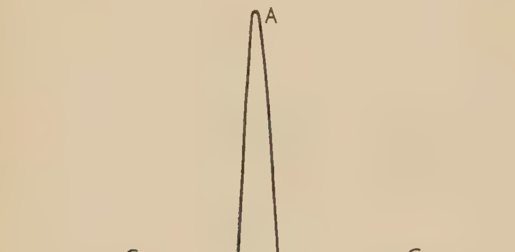


Fig. 3. Variation of photocell current with relative displacement of grating and image. Grating line-width approximately 0·03 mm

4. AMPLIFICATION AND PRESENTATION OF THE PHOTOCELL SIGNAL

In addition to the principal photocell, P_1 (Fig. 1), directl behind the receiving grating C, a second photocell, P_2, attached to the tube CD to receive a proportion of the ligh directed towards C. The signals from these two photocel are applied to the grids of two valves, V_1 and V_2, as show in Fig. 4. The valves together with their anode and cathod resistors form the arms of a bridge with a sensitive galvan meter G connected between their anodes to indicate condition of balance. A variable resistor R in the cathod circuit of V_2 is provided for balancing the bridge when bo photocells are masked. The amount of light received by is adjusted initially so that its signal is equal to that from at a reference level about midway between maximum an minimum, and the sensitivity at this level is such that 1 (4 × 10^{-5} in.) movement of the probe can be made produce 1 cm movement of the galvanometer spot. Ther are, of course, two positions of the probe corresponding the reference level, distinguishable by the direction of th change of galvanometer deflexion, and provided that a conditions are stable, either might be adopted as the "set indication for the probe. It is evident that in this conditio as both photocells are giving equal signals, fluctuations in th intensity of the light source will not disturb the equilibriu of the bridge. However, should a portion of the reflectin surface being observed change its reflectivity, then, sinc both photocells are receiving partially focused light, loca areas of their cathodes will be differently affected, and the cathodes are not necessarily uniformly sensitive this ma vary the photocell signals by different amounts and thu alter the balance of the bridge. This has the effect of shiftin the whole photocell current/grating displacement curve (Fig. vertically, and whilst the maximum A and the minima and B_2 still occur at the same probe positions, the referenc level no longer has the same significance. It is therefor advisable to make two probe settings, one on each slope the reference level, and to adopt the mean position as th "set" position for the probe; this mean position will remai unchanged, the two slopes having closely equal gradients.

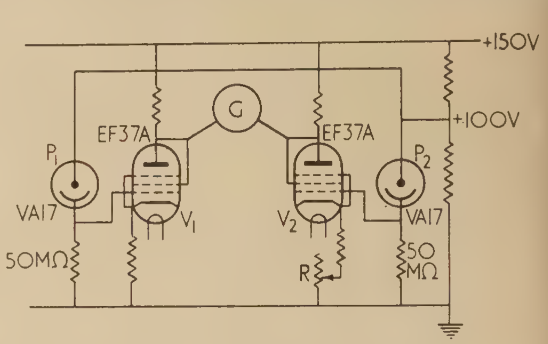
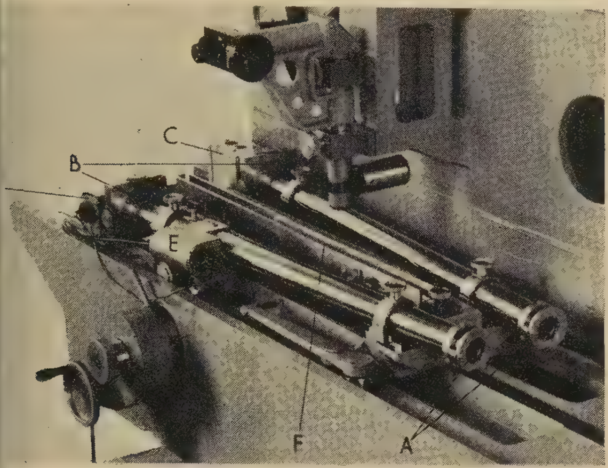


Fig. 4. Bridge-amplifier circuit

The galvanometer has a double beam indication, givin scale deflexions of 1 mm/μA and 10 mm/μA; this enabl n the initial search for coincidence and the final precise itioning of the probe to be carried out with ease.

DETAILED DESCRIPTION OF A PROBE UNIT

photograph of a probe unit as employed on the new nary standard barometer at the National Physical oratory is shown in Fig. 5.



ig. 5. Probe unit as employed on the new primary tandard barometer at the National Physical Laboratory

he projector lenses, which are edge-contact achromatic blets, can be seen at *A* mounted on the probe tubes ch are supported in vees and clamped in position on a iage. At the rear end of the tubes can be seen the grating lers *B*, square in form, which provide vertical, lateral and itional adjustment (the control screws for the last are cured). The ventilated box *C* contains a low-power gsten filament lamp which illuminates the first grating ough a condenser lens whose principal focus is mid-way ng the tube. The photocell *D* is contained in a light-tight provided with an aperture adjacent to the second grating. balancing photocell in a light-tight box *E* attached to the of the tube is illuminated by means of a lightly alu-ized glass plate set at 45° within the tube.

he probe carriage is supported between horizontal parallel leways formed in the upper surface of a massive casting, and slow motion controls being provided for moving unit along the length of the casting. Supported on ers, in the centre of the carriage, is a 50 cm line standard which is adjusted to lie level and along the line of motion he probe. Movement of the probe between successive ings may be determined by the micrometer microscope ched to the main casting and trained on the line standard.

CONSIDERATION OF THE ERRORS OF THE PROBE

he fundamental principle of the optical probe described ection 2 assumes that the system is exactly symmetrical that the bisector of the probe angle is exactly normal to reflecting surface. In practice these ideal conditions not be wholly achieved due to lack of straightness of the be carriage ways and limitations in the initial adjustment he optical system.

ig. 6 represents a condition of asymmetry. mm' is the ne mirror surface whose position is to be ascertained by the probe and AB is a normal to mm' passing through the intersection O of the optical axes of the two probe tubes which are inclined to each other at the angle 2θ. T is a point on a line of the first grating and R is the corresponding point on the second or receiving grating, the grating lines being normal to the plane of the diagram. M_1, M_2, N_1, N_2, represent the nodal points of the lenses in the two tubes, N_2O and M_2O being parallel to TN_1 and RM_1 respectively. The image I of T will fall on N_2O (or its extension) and any point on M_2O will form an image on RM_1. Ideally I should be at O and M_2O and N_2O should be equally inclined to the normal. The figure represents the condition when there is an error ϕ in the inclination of the tubes to AB, I is displaced a distance p from O and the probe is "set" so that the final image of T is in exact coincidence with R.

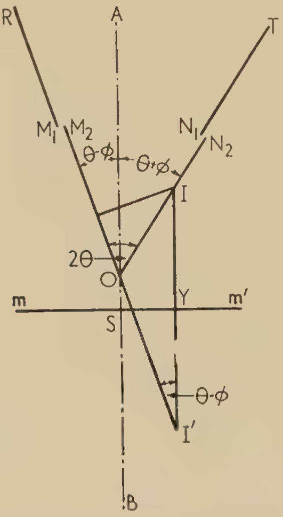


Fig. 6. Effect of errors in adjustment of probe $OI = p$; $OS = s$

I will form an image at I' where II' is normal to the mirror surface and $IY = YI'$. Because the probe is "set," I' falls on M_2O produced. OS represents the amount, s, by which the apex of the probe is separated from mm'. The final image will not be exactly in the plane of the grating R, but the departures from ideal conditions will be so small that the effects of lack of correct focus can be ignored and only variations in s due to changes in ϕ need be considered. It can readily be established from the construction shown that

$$2s \sin(\theta - \phi) = p \sin 2\phi \qquad (1)$$

$$\therefore \quad 2\sin(\theta - \phi)\Delta s = 2p\cos 2\phi\Delta\phi + 2s\cos(\theta - \phi)\Delta\phi \qquad (2)$$

As ϕ is extremely small compared with θ,

$$2\sin\theta \,.\, \Delta s = 2p\cos 2\phi \,.\, \Delta\phi + 2s\cos\theta \,.\, \Delta\phi \qquad (3)$$

Substituting the value of s from (1) in (3), and again neglecting ϕ in relation to θ

$$\Delta s = \frac{p}{\sin\theta}\left(\cos 2\phi + \frac{\sin 2\phi}{2\tan\theta}\right)\Delta\phi \qquad (4)$$

By way of illustration it is convenient to consider the particular probe described. Here $\sin\theta = 1/12$ and p, which is dependent upon the adjustment of the optical system, was set initially to be less than 100 μ. Although p changes by about 15 μ/°C, due principally to changes in focal length of the lenses with temperature, even with temperature variations of $\pm 5°$ C from normal its value would be expected never to exceed 200 μ. We have then,

$$\begin{aligned}\Delta s &= 2400\,(\cos 2\phi + 6 \sin 2\phi)\Delta\phi\ \mu \\ &= \text{closely } 2400\,(1 + 12\phi)\Delta\phi\ \mu \qquad (5)\end{aligned}$$

ϕ can be set to be less than 1 minute of arc or 3×10^{-4} rad, and tests have shown that ϕ remains constant well within 8 seconds of arc over the 50 cm movement of the probe, i.e. $\Delta\phi \ngtr 4 \times 10^{-5}$ rad; hence Δs, the variation in apparent mirror position due to variations in p and ϕ, need not exceed 0·1 μ. This estimate of the effect of variations in ϕ due to lack of straightness of the ways in which the probe mov assumes of course that the reflecting surface moves accurate parallel to itself. In our particular application this is alwa the case, as the probe is used to measure the displacement a large free mercury surface.

Table. *Measured distance (mm) between two reflecting surfaces*

Group of observations	*Result (mm)*	*Means (mm)*	*Group variances* (μ^2)
1	467·3599		
	467·3591		
	467·3603	467·3595	0·27
2	467·3593		
	467·3590		
	467·3592		
	End gauge reassembled		
3	467·3606		
	467·3596		
	467·3598		
4	467·3600	467·3601	0·25
	467·3597		
	467·3608		
	End gauge reassembled		
5	467·3603		
	467·3607		
	467·3611		
6	467·3592	467·3603	0·40
	467·3604		
	467·3603		
Means	467·3600		0·31
Variance	0·41 μ^2		

7. PERFORMANCE OF THE PROBE

The particular probe described in Section 5 was used measure the distance between reflecting surfaces formed two flat and parallel steel slips 0·4 in. thick, separated by 18 in. combination end gauge; by conventional methods measurement the separation of the two surfaces was know to be 467·3600 mm ± 0·0005 mm at 20° C. The measu ments were taken in groups of three and after alterna groups the combination end gauge was dismantled and made. The results of the observations, corrected for te perature and for known errors of the probe line-standa are tabulated in the table .

The range of 0·8 μ between the three mean values for measurement may be attributed in part to small variations the reconstitution of the end gauge. Since the varia associated with the calibration of the line-standard is abo 0·1 μ^2 it is evident from these results that if all known systematic errors are eliminated the probe described is capa by an individual measurement, of determining the displa ment of a reflecting surface with a standard deviation larger than 0·7 μ (0·000028 in.). It should be noted such accuracy is contingent upon the probe and reflecti surface being adequately protected from all draughts wh vary the refractive index of the air between the lenses of probe and its apex.

8. ACKNOWLEDGEMENTS

The conception of the optical probe was due to the la Mr. F. D. Jones of the Metrology Division of the Natio Physical Laboratory. The assistance afforded him by Light Division in the early stages of the development of instrument is acknowledged. The present authors al acknowledge the advice and assistance given them by th immediate colleagues. The work was carried out as part the research programme of the National Physical Laborato and this paper is published by permission of the Director the Laboratory.

The design of an apparatus for biological experiments at high hydrostatic pressure

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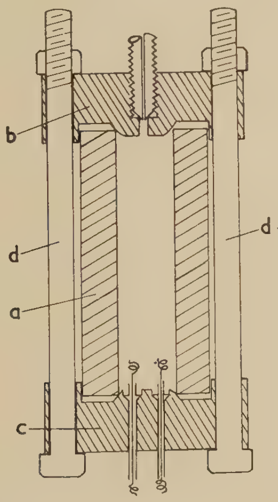
A very simple and cheap design is described that can be used up to 1 000 atm. The stainless steel pressure chamber is provided with six insulated Pyrotenax leads and a permeability bridge for measuring mechanical changes. It has been used for recording the tension developed by a stimulated muscle but could be readily adapted to suit other experimental requirements.

n hydrostatic pressure is known to influence muscular raction (see, for example, Brown and Sichel).(1) In order ake further observations on this subject it was necessary onstruct apparatus to record the mechanical response of ted frog muscles stimulated electrically in Ringer's fluid igh pressure.

he physiologically interesting range of pressure is from to about a thousand atmospheres, and although Bridg- (2) in his admirable book gives details of technique licable up to much higher pressures, he does not make r what is the *simplest* solution to this comparatively lest problem. It was necessary to perform a good deal levelopment work before we arrived at a final design ch combined cheapness and simplicity with reliability ease of manipulation.

1. THE PRESSURE CHAMBER

wo chambers were constructed, a large one (capacity ml, weight 33 kg), then a small one (capacity 67 ml, ght 7·7 kg). Only the small chamber will be described etail, since it was used in most of the experimental work. onsists of three main parts (see Fig. 1), a cylindrical re section *a* that is clamped between circular end-pieces, nd *c* by high-tensile steel bolts *d*. (One of these had been ed and found to yield at 9·4 tons weight.) The chamber nade of high-tensile stainless steel type *R*2 (end pieces) and *R*4 (centre section) supplied by W. Jessop and Sons Ltd., and heat-treated by them to tensile strength 45/55 tons weight/in.^{2} for *R*2 and 55/65 tons weight/in.^{2} for *R*4. Both types contain about 15% chromium and are quite easy to machine with tungsten carbide tools.



ig. 1. Longitudinal section through pressure chamber

, cylindrical centre section; *b*, lower end-piece fitted with sulated electrodes; *c*, upper end piece, with connecting pipe pressure pump; *d*, high-tensile steel bolts which clamp the three parts of the chamber together.

In such a complex structure few of the stresses can be calculated with accuracy; during early tests of performance the strain in the chamber was monitored by winding the cylindrical centre section tightly with fine Nichrome wire. This formed one arm of a Wheatstone's bridge, and since the relative resistance change is once or twice the relative strain, the strain could be roughly calculated in absolute terms. The centre section was found to expand by 0·007% under 210 atm, reversibly and without creep, implying that the material was well within its elastic limit.

The critical point of the whole design is the way in which the three parts of the chamber are joined together in use by pressure-tight seals. A number of experiments with copper, lead and Neoprene gaskets convinced us that these did not provide a satisfactory solution to the problem. Since a fairly large area of the gasket was clamped, the "hydrostatic" pressure in the gasket produced by tightening the bolts was less than the pressure inside the chamber, so leakage always occurred, leading eventually to blowing of the gasket. It is much better to use a plain metal-to-metal joint with a very small contact area, as shown in Fig. 1, for along the circular line of contact between the inner sharp edge of the cylinder and the curved surface of the end piece, the contact pressure is very great indeed, and leaking is prevented. It is not necessary for the surfaces in contact to be particularly highly finished, since in use the stresses along the line of contact are great enough to cause plastic deformation of the metal, which itself becomes burnished to a high finish. These joints have now been made and broken more than a hundred times without impairing their surfaces; but if they should become damaged it would be a simple matter to renew them by machining off the faulty portion.

2. PUMP AND PIPING

Suitable hand-pumps, pipes and gauges are available at reasonable prices from commercial sources, for they are used in testing the fuel injector systems of Diesel engines. We have used a Varley model HPT 30 pump, slightly modified by the manufacturers to produce pressures above its normal range. This has been altogether satisfactory.

3. INSULATED LEADS

In order to stimulate the muscle and record its response insulated leads must pass through one of the end-plates of the chamber, and the insulating material used for this purpose is subjected to very great shearing stresses. The types of insulated lead described by Bridgman all occupy a considerable area and could not be used since we wished to fit six electrodes into a small area. The technique finally adopted was based on the use of Pyrotenax cable, following a suggestion from the I.C.I. research laboratory at Winnington. In this cable, designed for use at high temperature, an inner wire is insulated from an outer protective copper sheath by a layer of magnesium oxide; the bond between metal and oxide is very strong. Our electrodes were made by brazing the outer copper sheath to a small brass cone which fitted a seating formed in the end-piece of the chamber. The pressure forces the cone on to this and a thin (0·006 in.) interposed lead disc ensures a liquid-tight seal. The internal cross-section of the copper tube is only about 0·06 in. so that even with an internal pressure of 1 000 atm, the maximum shearing force is approximately 40 lb weight, which the magnesium oxide is well able to withstand. The only drawback to the use of Pyrotenax is that the insulation is very hygroscopic and when damp the insulation resistance falls to a few thousand ohms. However, it can be restored again by applying a high voltage between wire and casing, or, more satisfactorily, by baking the whole assembly above 100° C for half an hour; this is very inconvenient in practice and it is essential to seal the ends of the electrodes against the ingress of moisture. The manufacturers recommend that this should be done with a glass bead, but the glass was found to crack when pressure was applied. A more satisfactory seal for our purpose was obtained by scraping out the insulation at the ends of the electrode and filling the space with Araldite D epoxy resin (by Aero Research Ltd.)

4. THE MUSCLE CHAMBER

The pump and pipes must be filled with oil (a light mineral oil sp. gr. = 0·85 was used), but the muscle must be bathed in Ringer's fluid if it is to survive well. It was found to be extremely difficult in practice to maintain insulation resi tances in the presence of Ringer's fluid at high pressure, s the space within the chamber was subdivided into tw compartments, an inner, Ringer-filled one containing th muscle and an outer one filled with oil in which all electric connexions were made (see Fig. 2). The inner chamber could be closed by a thin piece of Polythene sheet *d* clampe by a Perspex ring. There is a volume change of one ml whe the fluid in this inner chamber is compressed under 800 atm and in order to allow for this a dome is formed on the Poly thene by stretching it over the bottom of a large test tub containing boiling brine. If the chamber is used in a vertic position this cover can be dispensed with. The muscle, frog's sartorius *e*, is clamped at its pelvic end. It lies on a array of stimulating electrodes *f* and its tibial end is attache to a transducer *h* to measure the tension.

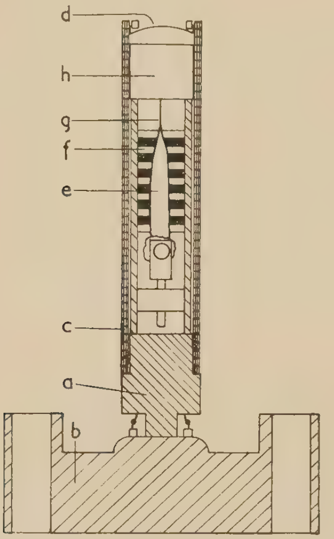


Fig. 2. Scale diagram of inner chamber

The base of the inner chamber *a* is rigidly attached to the lower end-piece *b* and over it is fitted a methacrylate polymer (Perspex) chamber *c* which can be closed by a flexible Polythene dome *d*. This is completely filled with Ringer's fluid and contains the sample, in this case a muscle, a frog's sartorius, clamped at its pelvic end and lying on an array of stimulating electrodes *f*. The tibial end of the muscle is attached to the transducer *h* (see Fig. 3) in order to record tension development.

Oxygen supply. Unfortunately it is not practicable t supply the inner chamber with a continuous stream of oxygen though Ringer's fluid was saturated with oxygen before th beginning of each experiment. The total amount of oxyge in solution would be enough to sustain continuous contractio for several hours, and since all the experiments involved much lower level of energy production, there was no reaso to suppose that the oxygen tension fell enough during a experiment to interfere substantially with the diffusio gradient on which the inner parts of the muscle must depen for their supply.

5. THE TRANSDUCER

In spite of the precautions taken to keep Ringer's fl out of the oil compartments, it proved impossible to mainta reliable high insulation resistances. Insulating mater which work well at ordinary pressures, e.g. Bakelite varnis are penetrated by Ringer's fluid, at high pressure. Probab differential compression of the insulation and of the unde lying metal causes the former to develop minute cracks. Th best coating material found was Araldite D epoxy res which adheres extremely well to metal. Once it has poly merized it is inert and non-toxic. Not only do muscle survive well in contact with it, but tissue cultures gro perfectly well in Araldite dishes. However, even Araldit reinforced with Nylon fabric could not protect a small fiel coil from the effects of Ringer's fluid at 400 atm.

The pressure and the difficulty with insulation preclud one from using several familiar types of transducer, e.g. thos based on piezo-electric effects or on capacitance change Several types of transducer based on resistance measuremen or on magnetic permeability bridges were tried and discarde

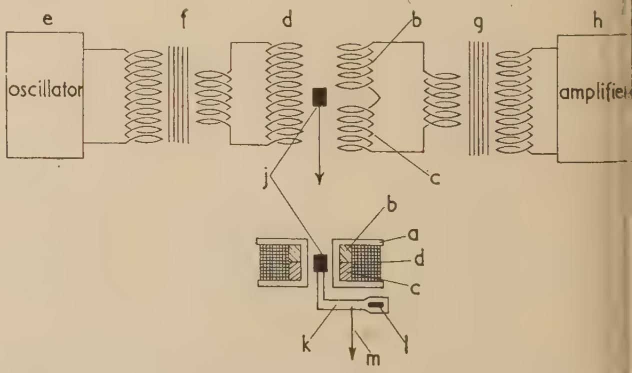


Fig. 3. Circuit diagram (above) and sectional drawing (below) of transducer. For details see text

re arriving at the design shown in Fig. 3. Fundamentally is a simple type of magnetic permeability bridge conng of a bobbin *a* wound with two exactly similar coils d *c* whose turns run in opposite directions. On top of i is wound a uni-directional field coil *d*. Current at c/s is generated by an oscillator *e* and fed to the field through a matching transformer *f*; it induces equal and osite voltages in coils *b* and *c*. Axial movement of a ll piece of soft iron *j* shifts the magnetic flux into one or other half of the detector coil so that a net output current ears. This is passed through a matching transformer *g* i amplified, rectified and displayed on a cathode-ray e *h*.

he piece of soft iron is attached to a beryllium-copper ion band (1) through a lever *k* to which the muscle is connected (*m* in Fig. 3, *g* in Fig. 2). When the muscle elops tension the torsion band is twisted and the piece of iron moves downwards (and slightly sideways) within bobbin. The total movement is less than 0·1 mm for greatest tension encountered.

he virtue of this transducer, apart from its simplicity, lies he fact that its magnetic circuit contains very little iron. mpedance is therefore only a few ohms at 20 kc/s and is e unaffected by insulation leaks of a few thousand ohms. It was found necessary to run the heaters of the oscillator from batteries in order to eliminate modulation hum. Although the viscosity of oil increases considerably with pressure the moving system when immersed was not excessively damped. It had a natural period of 10 ms, and was linear over the whole of its usable range.

The transducer could easily be modified to measure some other mechanical variable, e.g. changes of length of several millimetres. This, and the ease with which electrical connexions can be made and broken, makes the whole apparatus easily adaptable for many different purposes.

ACKNOWLEDGEMENT

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Counter diffractometer—the effect of vertical divergence on the displacement and breadth of powder diffraction lines

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The "vertical" divergence of the beam in a counter diffractometer causes a broadening, and a shift of centre of gravity, of diffraction lines. The effects do not disappear as 2θ tends to 180°, and hence present extrapolation methods fail to remove the errors introduced. Experimental results are quoted that are not explained by previous treatments, and a theoretical investigation is made of the diffractometer with no Soller slits, one set of slits, and two sets of slits. Results show a marked asymmetry about $2\theta = 90°$, both in shift of centre of gravity and in line broadening, the maximum effects occurring at low values of 2θ.

The use of Soller slits for various practical applications of the diffractometer is discussed. For accurate lattice-parameter measurement it is shown that the fractional error in spacing introduced by vertical divergence may be written in the form

$$\Delta d/d = -a + b\cos^2\theta$$

where a and b are positive constants depending on goniometer radius, specimen height, and Soller-slit aperture (if used). Extrapolation against $\cos^2\theta$ and addition of the constant a will therefore give the true lattice spacing. The magnitude of the correction for a "Norelco" high-angle goniometer with two sets of Soller slits is approximately 4 parts in 10^5.

1. INTRODUCTION

e use of the counter diffractometer for the precision asurement of lattice parameters is becoming more wideead, and the instrument gives promise of accuracy superior hat obtainable by camera techniques. One of its advanes for this work is that the positions of centres of gravity diffraction lines may be obtained accurately without the jective errors which are unavoidable with film measureit. As with the powder camera, however, it is desirable employ an extrapolation technique. This process allows errors due to divergence of the primary beam in the plane Bragg focusing (flat-specimen error), specimen transency, and specimen surface displacement.(1) It does not nove errors introduced by the divergence of the primary and diffracted beams out of the plane of focusing, usually termed vertical divergence, after Wilson(1) and Eastabrook.(2) This error unfortunately does not vanish at $2\theta = 180°$, and present methods of dealing with vertical divergence aberrations aim at minimizing them, either by avoiding large divergences, or by using the well-known Soller slits.(3)

An analytical treatment has been attempted by Eastabrook.(2) His analysis, however, does not take account of the finite "heights" of source, specimen, and receiving slit, but considers them as a section of a diffractometer with infinite vertical dimensions. He points out that there will be "end effects," but incorrectly assumes that they will be small; unfortunately, therefore, his results do not apply to cases met in practice.

Klug and Alexander[(4)] quote Eastabrook's results, but also state that the introduction of Soller slits *increases* distortion of line profile due to vertical divergence at angles above $2\theta = 90°$. However, since Soller slits can only *decrease* beam divergence in the vertical plane, this statement appears to be in error.

Wilson[(5)] finds the relation between the departure from the true Bragg angle and the vertical dimensions of source, specimen, and receiving slit, his expression, equation (51) of ref. (5) agreeing with Eastabrook's equation (12) of ref. (2). Beyond this geometry of the problem he quotes Eastabrook's[(2)] discussion of its application to the counter diffractometer, but suggests that a further investigation should be made of the following two points:

(i) the use of one set of Soller slits only,
(ii) the region near $2\theta = 90°$.

W. Parrish of Philips' Laboratories, Irvington, New York, has kindly performed some careful experimental work on the effect, and has provided the author with the data contained in Table 1.

Experimental facts which are not explained by Eastabrook are that there is a distinct displacement of the centre of gravity of a diffraction line towards low angles at $2\theta = 90°$, whereas his analysis predicts no displacement here; and the shifts at $2\theta = 20°$, and $2\theta = 160°$, which Eastabrook finds equal and opposite, are found in fact to be very different in magnitude.

Table 1. *Vertical divergence measurements*

Experimental conditions:

Standard "Norelco" diffractometer. Copper target, 40 kVp, 0·0007 in. Ni filter, line focus viewed at $\psi = 6°$. Scintillatio counter, with pulse height discrimination. Curves replotted from fixed count measurements made with counting rat computer. Each set of parallel slits 0·50 in. long and 0·020 in. spacers.

Specimens: Lead nitrate, flat rotating specimen, 111α; silicon, flat stationary specimens, $444\alpha_1\alpha_2$, $620\alpha_1\alpha_2$.

Specimen	*Line*	*2α*	*Parallel slits* *1st set*	*2nd set*	*Receiving slit width in.*	*C.G.*	*Peak*	*Width (° 2θ)* *1/2*	*1/4*
$Pb(NO_3)_2$	111α	1°	In	In	0·006	19·490	19·519	0·113	0·183
$Pb(NO_3)_2$	111α	1°	Out	In	0·006	19·457	19·510	0·125	0·229
$Pb(NO_3)_2$	111α	1°	Out	Out	0·006	19·404	19·509	0·144	0·290
									(α_1 only)
Si	$620\alpha_1\alpha_2$	4°	In	In	0·012	127·648	127·458	0·188	0·312
Si	$620\alpha_1\alpha_2$	4°	Out	In	0·012	127·644	127·450	0·200	0·324
Si	$620\alpha_1\alpha_2$	4°	Out	Out	0·012	127·639	127·448	0·206	0·330
Si	$444\alpha_1\alpha_2$	4°	In	In	0·012		157·540		
Si	$444\alpha_1\alpha_2$	4°	In	Out	0·012	Width large due to spectral broadening but shift of			
Si	$444\alpha_1\alpha_2$	4°	Out	Out	0·012	centre of gravity ≃ 0·01° to high 2θ			

2. THEORETICAL TREATMENT

A comprehensive theoretical analysis is clearly desirable, and expressions for the shift of centre of gravity and line-broadening have therefore been derived for a diffractometer equipped with two sets of Soller slits, with one set, and with no Soller slits.

2.1. *Diffractometer with no Soller slits*

2.1.1. *Geometry*

We consider the problem of a diffractometer with source "height" $2F$, receiving-slit "height" $2R$, and with a correctly-set rectangular flat specimen of "height" $2P$. We let th diffractometer radius be s, and take the origin of coordinates O at the centre of the front face of the specimen The axes of x, y, and z, unit vectors along which are $\boldsymbol{i}, \boldsymbol{j}$, and $\boldsymbol{k}$ are taken as shown in Fig. 1. The variables f and r denot

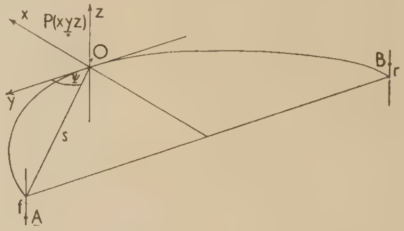

Fig. 1. Geometry of the diffractometer

points A, B on the focus and receiving slit respectively, and a point P within the specimen is denoted by the variables x, y, z. Using Wilson's[(1)] notation, we let the diffractomete be set for reflexion at the angle ψ, where $\psi = \theta - \varepsilon$ and ε i small. Following Wilson[(1)] we consider reflexion from th point P, where the mis-setting of the reflecting crystal grai is δ, but we now allow P three degrees of freedom instead o Wilson's two.

We first need to find δ as a function of ε, x, y, z, f, and p. Now δ is defined by the relation

$$2(\theta - \delta) = 2\pi - \angle APB \qquad (1$$

thus, to the first order in δ

$$\cos 2\theta + 2\delta \sin 2\theta = -\cos \angle APB \qquad (2$$

i.e.

$$\delta = (-\cos \angle APB - \cos 2\theta)/2 \sin 2\theta \qquad (3$$

but

$$\cos (\angle APB) = \frac{\boldsymbol{PA} \,.\, \boldsymbol{PB}}{|\boldsymbol{PA}||\boldsymbol{PB}|} \qquad (4$$

and

$$\boldsymbol{PA} = (-s \sin \psi - x)\boldsymbol{i} + (s \cos \psi - y)\boldsymbol{j} + (f - z)\boldsymbol{k} \qquad (5$$

$$\boldsymbol{PB} = (-s \sin \psi - x)\boldsymbol{i} + (-s \cos \psi - y)\boldsymbol{j} + (r - z)\boldsymbol{k} \qquad (6$$

Thus to the first order in ε

$$= \varepsilon - \frac{x}{s}\cos\theta - \frac{y^2}{s^2}\sin\theta\cos\theta - \frac{z^2}{2s^2}\cot\theta - \frac{f^2}{4s^2}\cot 2\theta$$

$$- \frac{r^2}{4s^2}\cot 2\theta - \frac{fr}{2s^2}\operatorname{cosec} 2\theta + \frac{zr}{2s^2}\cot\theta + \frac{zf}{2s^2}\cot\theta \qquad (7)$$

1.2. *Displacement of centre of gravity*

After Wilson(1) again, we suppose the efficiency of reflexion a crystal grain in the reflecting position, when the angle of cidence of the X-ray beam is $\theta + \delta$, to be $\mathrm{f}(\delta)$ where

$$\int_{-\infty}^{+\infty} \delta \,.\, \mathrm{f}()\, \delta \,.\, d\delta = 0 \qquad (8)$$

ld

$$\int_{-\infty}^{+\infty} \mathrm{f}(\delta) \,.\, d\delta = 1 \qquad (9)$$

The absorption factor is again $\exp(-2\mu x \operatorname{cosec}\theta)$ to the st order in μx, and using Wilson's notation we write

$$2\,\mu \operatorname{cosec}\theta = M \qquad (10)$$

We now consider the intensity, δI, diffracted by an element volume $\delta x\delta y\delta z$ in the specimen, from an element δf on e source into an element δr of the receiving slit during a splacement of the goniometer to the position $\psi + \delta\varepsilon$ at nstant angular velocity.

We find

$$\delta I(\varepsilon) \,.\, \delta\varepsilon = \mathrm{f}(\delta)\exp(-Mx) \,.\, \delta x\delta y\delta z\delta f\delta r\delta\varepsilon \qquad (11)$$

d integrating over all values of ε, over the finite heights of ecimen, source, and receiving slit, and over the illuminated rtion of the specimen (see Wilson's(1) footnote), we have:

$$\langle\varepsilon\rangle = \frac{\int \varepsilon \,.\, I(\varepsilon) \,.\, d\varepsilon}{\int I(\varepsilon) \,.\, d\varepsilon} \qquad (12)$$

$$= \frac{\iiiint\!\!\iint \varepsilon \,.\, \mathrm{f}(\delta) \,.\, \exp(-Mx) \,.\, dxdydzdfdrd\varepsilon}{\iiiint\!\!\iint \mathrm{f}(\delta) \,.\, \exp(-Mx) \,.\, dxdydzdfdrd\varepsilon} \qquad (13)$$

We must now assume that the irradiated length of the ecimen is independent of ε, for all values of this variable at hich appreciable reflexion will occur. In this case the limits integration of the six variables are all independent, and e above expression reduces rapidly to:

$$\rangle = \frac{\sin 2\theta}{4\mu s} + \frac{\alpha^2\cot\theta}{3} + \frac{\cot\theta}{6s^2}P^2 + \frac{\cot 2\theta}{12s^2}(F^2 + R^2) \qquad (14)$$

This is for an infinitely thick specimen with the irradiated ngth limited by the primary beam divergence 2α.

The first two terms will be recognized as the flat-specimen d absorption errors derived by Wilson,(1) whereas the last ree are new, and arise from the vertical divergence inherent the geometry.

A check on the vertical divergence terms is provided by king $\delta I(\varepsilon)$ directly proportional to δy, δr, and δp, and tegrating over these three variables only. We may then art from Eastabrook's(2) equation (12), which is equivalent Wilson's(5) equation (51)

$$\varepsilon = \tfrac{1}{4}(\alpha^2 + \beta^2)\cot 2\theta - \tfrac{1}{2}\alpha\beta\operatorname{cosec} 2\theta \qquad (15)$$

and substitute from his equations (7), which are, in the present notation,

$$\frac{p - f}{s} = \alpha, \quad \frac{r - p}{s} = \beta \qquad (16)$$

to obtain ε as a function of p, f, and r, obtaining

$$\varepsilon = \tfrac{1}{4}(2p^2 + f^2 + r^2 - 2pf - 2pr)\cot 2\theta -$$
$$- \tfrac{1}{2}(pr + pf - fr - p^2)\operatorname{cosec} 2\theta \qquad (17)$$

We may now find the displacement of the centre of gravity by using equation (12),

$$\langle\varepsilon\rangle = \frac{\iiint \varepsilon dfdrdp}{\iiint dfdrdp} \qquad (18)$$

which gives

$$\langle\varepsilon\rangle = \frac{\cot\theta}{6s^2}P^2 + \frac{\cot 2\theta}{12s^2}(F^2 + R^2) \qquad (19)$$

the result obtained above.

2.1.3. *Line-broadening*

The variance of ε, which is a measure of line-broadening,(6) is derived by calculating the mean value of ε^2 and subtracting from it the square of the mean value of ε.

$$\langle\varepsilon^2\rangle = \frac{\iiint \varepsilon^2 dfdpdr}{\iiint dfdpdr} \qquad (20)$$

This is easily evaluated for any particular values of F, P, and R, but the result will be quoted for the common case of $F = P = R$, say h:

$$\langle\varepsilon^2\rangle = \frac{h^4}{s^4}\left(\tfrac{1}{5}\cot^2 2\theta + \tfrac{4}{15}\cot 2\theta\operatorname{cosec} 2\theta + \tfrac{2}{15}\operatorname{cosec}^2 2\theta\right) \qquad (21)$$

The shift of centre of gravity in this case reduces to

$$\langle\varepsilon\rangle = \frac{h^2}{6s^2}(2\cot 2\theta + \operatorname{cosec} 2\theta) \qquad (22)$$

and the variance is

$$\langle\varepsilon^2\rangle - \langle\varepsilon\rangle^2$$
$$= \frac{h^4}{s^4}\left(\tfrac{4}{45}\cot^2 2\theta + \tfrac{7}{45}\cot 2\theta\operatorname{cosec} 2\theta + \tfrac{19}{180}\operatorname{cosec}^2 2\theta\right)$$
$$= \frac{h^4}{s^4}(0{\cdot}089\cot^2 2\theta + 0{\cdot}156\cot 2\theta\operatorname{cosec} 2\theta +$$
$$+ 0{\cdot}106\operatorname{cosec}^2 2\theta) \qquad (23)$$

2.2. *Diffractometer with one set of Soller slits*

We assume the parallel slits to be made up of infinitely thin foils, evenly spaced, with the spacing small compared with the vertical dimensions involved. The effect of such a set of parallel slits is (Eastabrook(2)—"Spectrometer with Soller slits") to reduce the intensity of rays leaving the focus at an angle α by a factor $(1 - |\alpha|/\Delta)$. It can be seen that this is independent of the actual position of the slits between the source and specimen; also, by the symmetry of equation (15) in α and β, we see that one set of slits will have the same effect, whether placed in the primary or the diffracted beam.

We consider the use of one set of Soller slits of aperture Δ (Δ = foil spacing/length), this set being placed in the primary beam. The calculation is much simplified for an instrument in which source, specimen, and receiving-slit, heights are all equal, say $2h$, and this case will be investigated. The calculation may be performed in a similar manner for other experimental arrangements.

2.2.1. *Displacement of centre of gravity*

We use the same notation as before, and introduce q as a measure of aperture defined by:

$$s\Delta = qh \qquad (24)$$

The symmetry about the x, y, plane allows us to consider only positive values of α in the calculation.

We need to express ε now as a function of α, p, and r, and this is readily done by use of equations (15) and (16), giving

$$\varepsilon = \frac{1}{4s^2}(\alpha^2 s^2 + r^2 - 2rp + p^2)\cot 2\theta + \frac{\alpha}{2s}(p - r)\operatorname{cosec} 2\theta \qquad (25)$$

The displacement of centre of gravity is now

$$\langle\varepsilon\rangle = \frac{\iiint \varepsilon(1 - \alpha/\Delta)\mathrm{d}\alpha\mathrm{d}p\mathrm{d}r}{\iiint (1 - \alpha/\Delta)\mathrm{d}\alpha\mathrm{d}p\mathrm{d}r} \qquad (26)$$

The integrations are taken over p and r as before, but over positive values of α limited by either the Soller-slit aperture or the finite heights of the source and specimen.

We consider diffraction from an element δp at a height p on the specimen. The beam may be diffracted to any point on the receiving slit with limits $-R \leqslant r \leqslant R$ independent of p. The beam from the source, however, may arrive from a positive angle α with an upper limit dependent on p and Δ as follows.

There are two cases to consider.

1. If $q \geqslant 2$, then, for all values of p between $+P$ and $-P$, α lies between 0 and $(P + p)/s$.

2. If $q \leqslant 2$, then

(*a*) for $-P \leqslant p \leqslant -P + qP$
$0 \leqslant \alpha \leqslant (P + p)/s$

and (*b*) for $-P + qP \leqslant p \leqslant +P$
$0 \leqslant \alpha \leqslant \Delta$

The integrations are therefore carried out between limits as above for α and r, and finally performed for p over the range $[-P, +P]$.

The results are:

1. $q \geqslant 2$

$$\langle\varepsilon\rangle = \frac{h^2}{6s^2}\left[\frac{(30q - 29)}{5(3q - 2)}\cot 2\theta + \frac{3(5q - 6)}{5(3q - 2)}\operatorname{cosec} 2\theta\right] \qquad (27)$$

2. $q \leqslant 2$

$$\langle\varepsilon\rangle = \frac{h^2}{6s^2}\left[\frac{(-12q^3 + 45q^2 - 40q + 120)}{20(6 - q)}\cot 2\theta + \right.$$

$$\left. + \frac{3(3q^3 + 10q^2)}{20(6 - q)}\operatorname{cosec} 2\theta\right] \qquad (28)$$

2.2.2. *Line-broadening*

The variance requires the evaluation of

$$\langle\varepsilon^2\rangle \doteq \frac{\iiint \varepsilon^2(1 - \alpha/\Delta)\mathrm{d}\alpha\mathrm{d}p\mathrm{d}r}{\iiint (1 - \alpha/\Delta)\mathrm{d}\alpha\mathrm{d}p\mathrm{d}r} \qquad (29$$

with the same limits of integration as above. The autho uses a modified "Norelco" high-angle goniometer for whic $q = 4/3$; the variance will be quoted for this value and als for $q = 2$, for comparison with later results.

$$q = \tfrac{4}{3},\ \langle\varepsilon^2\rangle - \langle\varepsilon\rangle^2 = \frac{h^4}{s^4}(0{\cdot}015\cot^2 2\theta -$$

$$- 0{\cdot}023\cot 2\theta\operatorname{cosec} 2\theta + 0{\cdot}032\operatorname{cosec}^2 2\theta) \qquad (30$$

$$q = 2,\ \langle\varepsilon^2\rangle - \langle\varepsilon\rangle^2 = \frac{h^4}{s^4}(0{\cdot}058\cot^2 2\theta -$$

$$- 0{\cdot}083\cot 2\theta\operatorname{cosec} 2\theta + 0{\cdot}062\operatorname{cosec}^2 2\theta) \qquad (31$$

2.3. *Diffractometer with two sets of Soller slits*

We consider the case of a diffractometer furnished wi two sets of Soller slits, one on each side of the specim each of aperture Δ, with q defined as above.

2.3.1. *Effect of second set of slits*

The effect of the second set of slits is rather complicat the weighting factor depending on α, β, Δ, and the relat *vertical* positions of the two sets of slits. For given values α, β, and Δ, this factor may have any value between two fix limits; these limits are functions of α, β, and Δ, and th actual value taken by the weighting factor between the depends on the relative *vertical* positions of the sets of slit The situation is best explained by means of a diagram, an for illustration, in Fig. 2 an instance is shown where th weighting factor, or transmission coefficient t, is zero. will be seen that vertical displacement of one set of slits wi alter the amount of radiation transmitted to the receivin slit. The maximum and minimum values of the transmissio coefficient t for a given Δ are functions of α and β, an may be represented by a closed envelope in the semi-infini space of t, α, and $|\beta|$. The shape of this surface is not easil drawn, but a section at a plane α = constant is drawn in Fig. Fig. 3(*a*) applies for $\alpha < \Delta/2$, and Fig. 3(*b*) for $\alpha > \Delta/$ Positive α only need again be considered for our calculatio by virtue of symmetry, but, of course, both positive an negative values of β are needed. The actual surface repre senting t as a function of α and β for a given relative positio of the slits will be within this envelope, taking the maximu and minimum values with the periodicity of the Soller-sl spacing along both the α and β directions. This surface wi

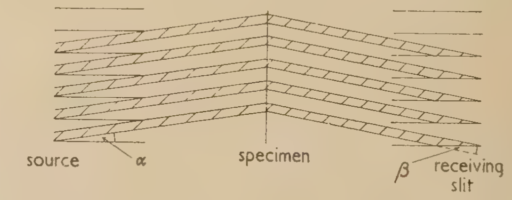

Fig. 2. The effect of the relative vertical positions of the Soller slits on the transmission coefficient. Here $t = 0$

o depend on the sign of β, although the envelope is a nction of $|\beta|$ only. If we investigate further, we may find e curve representing the intersection of this surface with the ne of Fig. 3, that is the value of t as a function of β for

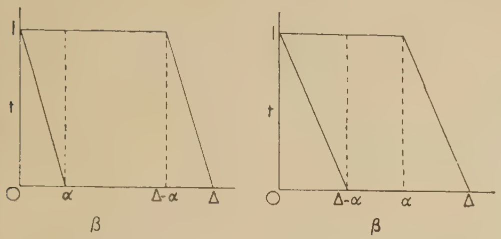

Fig. 3. The envelope of the function $t = f(\beta)$ for a given α: (*a*) $\alpha < \Delta/2$; (*b*) $\alpha > \Delta/2$

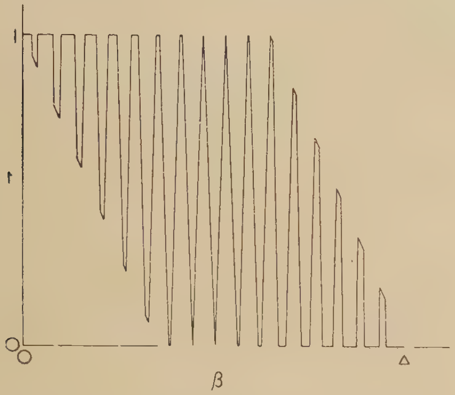

Fig. 4. A qualitative illustration of the variation of t with β

e given value of α (Fig. 4). This curve again depends on e relative Soller-slit positions, but gives a qualitative idea the variation of t with β. We shall be concerned to aluate integrals of the form

$$\int_\alpha \int_\beta \varepsilon(1 - \alpha/\Delta) \, . \, t \, . \, \mathrm{d}\alpha \mathrm{d}\beta$$

and clearly t is such a complicated function of α and β that it is impracticable to try to find it explicitly to use in the integrand. The only course open to us is to use a mean value, and we may justify this by (i) the high periodicity due to the large number of foils used to make up a set of slits, (ii) the averaging effect of the alteration of the envelope of the curve of Fig. 4 as α is varied, and (iii) by the important fact that experimentally no alteration of line profile is observed when the Soller slits are moved.

The average value of t is independent of α and is given by $t = (1 - |\beta|/\Delta)$. Physically, use of this average would apply to a diffractometer in which the second sets of slits is moved rapidly up and down in front of the receiving slit.

2.3.2. *Displacement of centre of gravity*

The obvious choice of variables in this case is α, β, and p We therefore use the value of ε as given directly by equation (15). We consider diffraction by an element δp at a height p on the specimen. The diffracted beam may now enter the receiving slit at an angle β between values also dependent on p and q. Again we take $P = R = F = h$. There are three cases to consider, which cover all possible Soller-slit apertures, and these, with the limits for α, β and p, are listed in Table 2.

The intensity reaching the receiving slit between β and $\beta + \delta\beta$ must be weighted by the factor $(1 - |\beta|/\Delta)$.

We have, therefore,

$$\langle \varepsilon \rangle = \frac{\iiint \varepsilon(1 - \alpha/\Delta)(1 - |\beta|/\Delta)\mathrm{d}\alpha\mathrm{d}\beta\mathrm{d}p}{\iiint (1 - \alpha/\Delta)(1 - |\beta|/\Delta)\mathrm{d}\alpha\mathrm{d}\beta\mathrm{d}p} \tag{32}$$

The integrals are split into the two ranges of positive and negative β, and the weighting factor $(1 - |\beta|/\Delta)$ then becomes $(1 - \beta/\Delta)$ and $(1 + \beta/\Delta)$ in the respective regions. The integrations are performed over the ranges listed in Table 2, and the results, which are rather lengthy, may be expressed in the following manner:

$$\langle \varepsilon \rangle = \frac{h^2}{6s^2}[Q_1(q) \cot 2\theta + Q_2(q) \operatorname{cosec} 2\theta] \tag{33}$$

where Q_1 and Q_2 are given in Fig. 5. Also plotted in Fig. 5

Table 2. *The limits of integration of the variables p, α, and β, when two sets of Soller slits are used*

q	α	p	β
$q \geqslant 2$	$0 \leqslant \alpha \leqslant \frac{P+p}{s}$	$-P \leqslant p \leqslant +P$	$-\left(\frac{P+p}{s}\right) \leqslant \beta \leqslant \frac{P-p}{s}$
$2 \geqslant q \geqslant 1$	$0 \leqslant \alpha \leqslant \frac{P+p}{s}$	$-P \leqslant p \leqslant P(1-q)$	$-\left(\frac{P+p}{s}\right) \leqslant \beta \leqslant +\Delta$
		$+P(1-q) \leqslant p \leqslant -P(1-q)$	$-\left(\frac{P+p}{s}\right) \leqslant \beta \leqslant \frac{P-p}{s}$
	$0 \leqslant \alpha \leqslant \Delta$	$-P(1-q) \leqslant p \leqslant +P$	$-\Delta \leqslant \beta \leqslant \frac{P-p}{s}$
$q \leqslant 1$	$0 \leqslant \alpha \leqslant \frac{P+p}{s}$	$-P \leqslant p \leqslant -P(1-q)$	$-\left(\frac{P+p}{s}\right) \leqslant \beta \leqslant +\Delta$
	$0 \leqslant \alpha \leqslant \Delta$	$-P(1-q) \leqslant p \leqslant +P(1-q)$	$-\Delta \leqslant \beta \leqslant +\Delta$
		$+P(1-q) \leqslant p \leqslant +P$	$-\Delta \leqslant \beta \leqslant \frac{P-p}{s}$

are the equivalent coefficients for the diffractometer with one set of Soller slits. Both pairs of curves are asymptotic, as q tends to infinity, to the values $Q_1 = 2$ and $Q_2 = 1$, which are the values previously obtained for the diffractometer with no Soller slits.

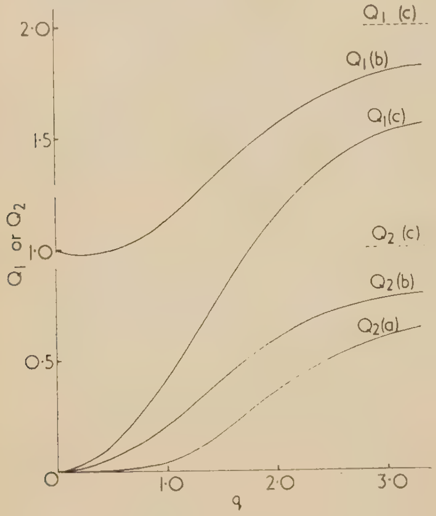

Fig. 5. The values of the coefficients Q_1 and Q_2 of equation (33): (*a*) two sets of Soller slits, (*b*) one set of Soller slits, (*c*) no Soller slits

2.3.3. *Line-broadening*

The variance for the diffractometer with two sets of Soller slits requires the evaluation of

$$\langle\varepsilon^2\rangle = \frac{\iiint \varepsilon^2(1-\alpha/\Delta)(1-|\beta|/\Delta)\mathrm{d}\alpha\mathrm{d}\beta\mathrm{d}p}{\iiint (1-\alpha/\Delta)(1-|\beta|/\Delta)\mathrm{d}\alpha\mathrm{d}\beta\mathrm{d}p} \qquad (34)$$

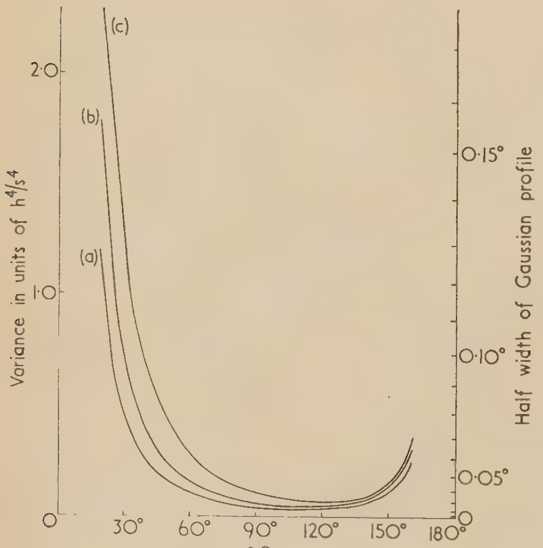

Fig. 6. Variance: (*a*) two sets of Soller slits, $q = 2$, (*b*) one set of Soller slits, $q = 2$, (*c*) no Soller slits. The scale of ordinates on the right-hand side of the figure gives the half width of a Gaussian profile for $2h = 1$ cm, $s = 17$ cm

This calculation is extremely long and tedious for genera values of q, but becomes tractable for the particular value o $q = 2$, and has been performed for this case only. The value obtained for the variance is

$$\langle\varepsilon^2\rangle - \langle\varepsilon\rangle^2 = \frac{h^4}{s^4}(0{\cdot}037 \cot^2 2\theta + $$
$$+ 0{\cdot}050 \cot 2\theta \operatorname{cosec} 2\theta + 0{\cdot}043 \operatorname{cosec}^2 2\theta) \qquad (35)$$

This expression is plotted in Fig. 6, together with the variance for one set of Soller slits, again with $q = 2$, an the variance for the diffractometer with no Soller slits.

3. DISCUSSION OF RESULTS

We may now review the results obtained, to decide upo the best practical means of countering the vertical divergenc effect.

The displacement of centre of gravity for a diffractomete without Soller slits is plotted as a function of Bragg angle i Figs. 7, 8, and 9. Use of the variable q ensures that th curves apply to any diffractometer, remembering only tha they have been calculated for instruments where the height of source, specimen, and receiving slit are all equal. Th angle scale (2 θ°) on the right of these figures applies onl to the "Norelco" goniometer, where $h = 0{\cdot}5$ cm, an $s = 17$ cm, but the appropriate angle scale for other instru ments may easily be inserted. It is seen that the shift c centre of gravity is quite asymmetrical about $2\theta = 9$ and is actually zero at $2\theta = 120°$. Inspection of Fig. shows that the broadening also has a flat minimum her and that the asymmetry is very marked. The broadenin increases rapidly at low Bragg angles but remains reasonab small right up to $2\theta = 160°$.

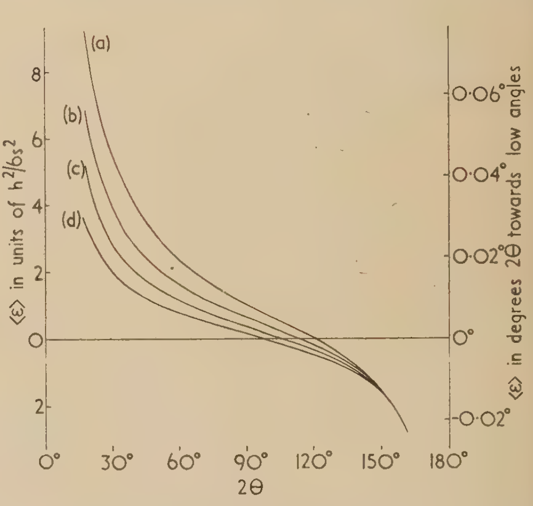

Fig. 7. Effect on shift of centre of gravity of inserting one set of Soller slits: (*a*) no slits, (*b*) one set, $q = 2$, (*c*) one set, $q = \frac{4}{3}$, (*d*) one set, $q = \frac{2}{3}$. The scale of ordinates on the right-hand side of the figure gives the displacement of centre of gravity for $2h = 1$ cm, $s = 17$ cm

Fig. 7 shows the effect of inserting one set of Soller slit only. Here we have an appreciable reduction in the shift c centre of gravity at low angles, which, however, cannot b reduced below the value

$$\langle\varepsilon\rangle = \frac{h^2}{6s^2}\cot 2\theta \qquad (36$$

owever small an aperture be used, as may be seen by spection of equation (25).

In the back-reflexion region the single set of slits does not ppreciably reduce either the shift of centre of gravity or e broadening. Indeed, in most of the region the shift of e centre of gravity is less without them, although, of course, e broadening is always reduced by the slits.

The effect of inserting two sets of Soller slits is shown in g. 8. With two sets of slits, as must be expected, decrease f Soller-slit aperture towards zero allows one to reduce the roadening and shift of centre of gravity to whatever extent s desired. In Fig. 9 we may compare the effects of no slits, ne set, and two sets of Soller slits for the particular value of = 4/3. If required, the value of q necessary to reduce the hift of centre of gravity to the order of the mechanical ncertainties in angular measurement may be calculated for any particular instrument by the use of equation (33) and the appropriate curves of Fig. 5. This would allow lattice parameters to be obtained by the current extrapolation methods. This course is not recommended by the author, however, and we shall now investigate the effect of vertical divergence on a normal extrapolation plot.

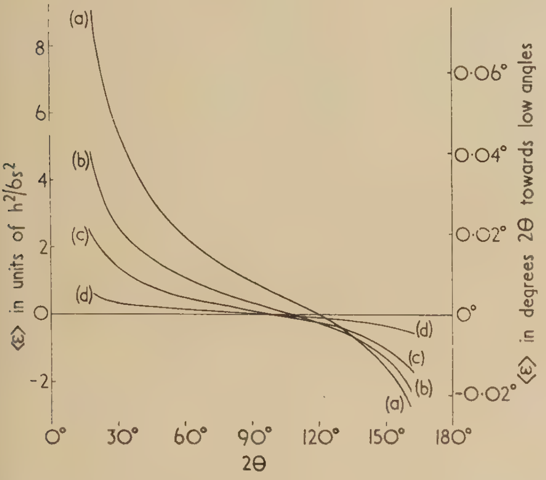

Fig. 8. Effect on shift of centre of gravity of inserting two sets of Soller slits: (*a*) no slits, (*b*) two sets, $q = 2$, (*c*) two sets, $q = \frac{4}{3}$, (*d*) two sets, $q = \frac{2}{3}$. The ordinates at the right are as in Fig. 7

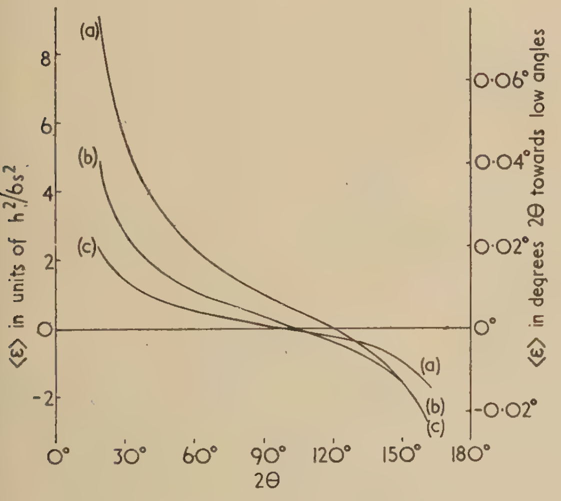

Fig. 9. Comparison of shift of centre of gravity with (*a*) no Soller slits, (*b*) one set of Soller slits, $q = \frac{4}{3}$, (*c*) two sets of Soller slits, $q = \frac{4}{3}$. The ordinates at the right apply to the "Norelco" goniometer as marketed. ($2h = 1$ cm, $s = 17$ cm, $q = \frac{4}{3}$)

The fractional error in spacing is found as follows:

$$\frac{\Delta d}{d} = -\cot\theta\Delta\theta = \frac{\cot\theta h^2}{6s^2}(Q_1\cot 2\theta + Q_2\operatorname{cosec} 2\theta) \qquad (37)$$

so that

$$\frac{\Delta d}{d} = \frac{h^2}{6s^2}\left(-Q_1 + \frac{Q_1 + Q_2}{2\sin^2\theta}\right) \qquad (38)$$

which may be written

$$\frac{\Delta d}{d} = -a + b\cos^2\theta + O(\cos^4\theta) \qquad (39)$$

where

$$a = \left(\frac{Q_1 - Q_2}{2}\right)\frac{h^2}{6s^2} \qquad (40)$$

and

$$b = \left(\frac{Q_1 + Q_2}{2}\right)\frac{h^2}{6s^2} \qquad (41)$$

Hence, on extrapolation against $\cos^2\theta$, a straight line will be obtained intersecting the $2\theta = 180°$ axis at a point less than the true value of d by the amount

$$\frac{h^2}{6s^2}\left(\frac{Q_1 - Q_2}{2}\right)$$

We see, therefore, that the "error" due to vertical divergence may be eliminated by performing the normal extrapolation against $\cos^2\theta$ and adding the above amount to the extrapolated value. This latter would be done at the same time as the refraction correction(7) is made.

The slope of the extrapolation plot, i.e. $h^2/6s^2[(Q_1 + Q_2)/2]$, is also a function of Soller-slit aperture, specimen height, and goniometer radius. Fig. 10 shows the form of the extrapolation plots for an instrument without slits, and also for the "Norelco" instrument both with two sets of slits, $q = 4/3$, and with one set removed. The slopes are small compared with the plots obtained with normal values of the other instrumental aberrations. For the "Norelco" diffractometer the correction to be applied after extrapolation is about 4 parts in 10^5 with the two sets in, and 7 parts in 10^5 with one or no sets. Thus the correction needs only to be known to ±10% for an accuracy in d of better than 1 part

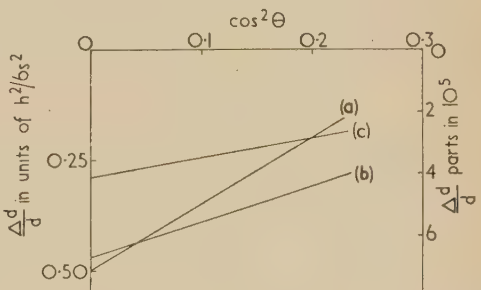

Fig. 10. Effect of vertical divergence on extrapolation plots: (*a*) no Soller slits, (*b*) one set of Soller slits, $q = \frac{4}{3}$, (*c*) two sets of Soller slits, $q = \frac{4}{3}$. The ordinates at the right apply to the "Norelco" goniometer ($2h = 1$ cm, $s = 17$ cm, $q = \frac{4}{3}$)

in 10^5. If accuracy greater than this is not desired, no great advantage is obtained by the use of two sets of slits. The procedure will work equally well with either one set or no slits, with the advantage of increased intensity, and hence more rapid scanning or better statistical accuracy. Dispensing with the set of slits in front of the source is not to be recommended, however, for reasons to be stated below.

4. PRACTICAL APPLICATION

Practically, of course, employment of Soller slits and reduction of Soller-slit aperture entail a marked reduction in recorded intensity, and a compromise solution must be found depending on which factor is the more important, line shape or intensity.

With modern counting detectors and circuits the intensity diffracted is the factor which limits counting times or scanning speeds; hence unnecessary waste of intensity, by the use of Soller slits where they may be dispensed with, or by using Soller-slit apertures which are unnecessarily small, must be avoided.

On the other hand, vertical divergence causes shifts of centres of gravity and broadening of diffraction lines which, for many applications, may be less desirable than losing a certain amount of intensity.

There is a third factor which is equally important although not immediately obvious. This is the use of such a set of slits, placed very close to the source, in reducing scattering and hence in improving peak to background ratios. The importance of the slits for this purpose has been emphasized by W. Parrish (private communication).

4.1. *Line-profile work*

For work in which line profiles are required, excessive vertical-divergence broadening, with its particular characteristic of giving long "tails" to lines, is not to be desired, and Soller slits of adequate aperture may be used. Clearly, from our previous results, we need two sets of slits, and if angles in the region $2\,\theta = 20°$ or lower are to be scanned, a suitable value of q would appear to be one giving $\langle\varepsilon\rangle$, from equation (33), $\simeq 0{\cdot}01°\,2\theta$. Lower values than this would probably not be worth while. Higher values of q will be more suitable for angles greater than, say, $2\,\theta = 60°$.

4.2. *Identification*

For this work both relative intensities and positions of lines are required. The important factor here is that it must be possible to compare on the same scale results obtained on very different instruments. The question of vertical divergence in this case poses a distinct problem, as the relative intensities of lines may well depend on the vertical divergence allowed, as also will the line positions. The shift of peak positions is less sensitive to vertical divergence than the shift of centre of gravity, but, whereas the positions of centres of gravity could be corrected for vertical divergence using the results of the previous analysis, and also can be corrected for other aberrations,(1) the shift of the peak is unknown and depends on other factors such as the distribution-in-wavelength of the X-ray beam.

Further experimental work is being done on this problem, but it would seem advisable at present to use a pair of Soller slits of such an aperture that *most* of the distortion of line profile is avoided, and hence discrepancies kept reasonably small. The removal of the second set of slits in the back-reflexion region would be advantageous in that scanning speed could be increased, but the difficulty of comparin intensities in the two regions, although not more difficu than comparing intensities in the same region from tw different instruments, would be introduced. For th "Norelco" goniometer an optimum value of q is provided b the point of inflexion of the curve for Q_1 for two sets of slits this occurs at $q \simeq 4/3$, and the soundness of the design c the "Norelco" instrument in this respect is remarkabl demonstrated.

4.3. *Lattice-parameter measurement*

It has been shown that errors introduced by vertical dive gence in lattice-parameter measurements may be eliminate by extrapolation in the normal manner against $\cos^2\theta$, an adding an amount $[(Q_1 - Q_2)/2]h^2/6s^2$ to the extrapolate value of d.

In this case there seems to be a distinct advantage in bein able to dispense with Soller slits in the diffracted beam. Th increase in intensity is extremely valuable, and the increas in broadening is very small. The effect of removal of th second set of slits is demonstrated in Fig. 11. The two curv are the result of automatic point-by-point monitore scanning(8) of the quartz (231) line at $2\,\theta \simeq 106{\cdot}6°$. It i seen that the intensity is practically doubled by removin the second set of slits, and the increase in half-width is to small to measure. The improved peak-to-background rati obtained by retaining the first set is probably of mor importance than the increase of intensity which woul accompany this removal. If accuracies beyond 1 part in 10 are aimed at, it will be necessary to use two sets of slits c aperture at least low enough to give $\langle\varepsilon\rangle$ at $2\,\theta = 160° \simeq 0{\cdot}005$ The correction on extrapolation would then be of the orde of two parts in 10^5.

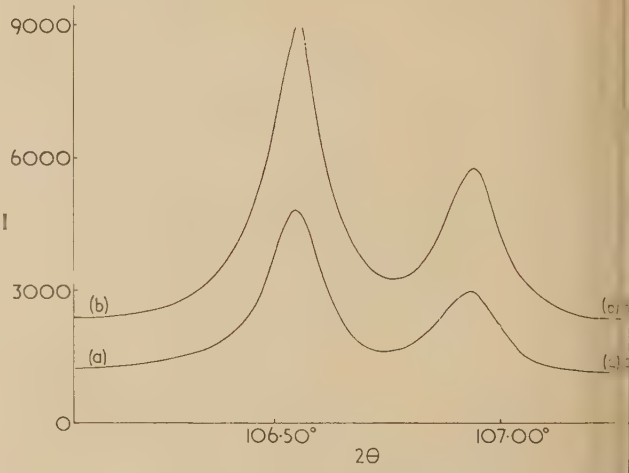

Fig. 11. Illustrating gain in intensity by removal of one set of Soller slits in the back-reflexion region. ("Norelco" goniometer.) (*a*) Two sets of Soller slits, (*b*) one set of Soller slits. The units of intensity are counts per 10,000 monitor counts

It has been suggested(9) that the use of a monochromat is advantageous for work on lattice-parameter measurements The advantage claimed is that its use reduces horizontal an vertical divergences to such an extent that extrapolatio becomes unnecessary. This procedure is not desirable however, as is shown by the following considerations.

(i) However small the beam divergences are, extrapolatio l still be needed to avoid the specimen-surface displace-ent error and the transparency error, which are not easily minated by other methods.

ii) The reduction in intensity involved by the use of a onochromator is such that very real advantages must be oved before contemplating its use for any purpose.

iii) Monochromatization by electronic methods using odern detectors may be used, without appreciable intensity s, if it is necessary to reduce background.

iv) The displacements of centres of gravity due to both rizontal and vertical divergence are now known, and there e advantages in working with reasonably small, known ors, rather than with unknown, though smaller, ones.

v) Against the evidence of the paper quoted,[(9)] the fact at the two extrapolation plots given intersect at the same int on the $2\theta = 180°$ axis indicates, on the basis of the ove analysis, that either negligible vertical divergence was esent before the introduction of the monochromator, or at there were present other effects such as specimen-surface splacement or specimen transparency which masked the rtical-divergence effect.

ACKNOWLEDGEMENTS

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A new self-recording rheogoniometer

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A rheogoniometer of the cone-and-plate type has been designed, in which either a continuous rotation or a simple harmonic motion can be imposed on the cone. The torque transmitted through the fluid, and also the normal thrust between the plates, are measured by capacitance gauges. The torque, thrust and applied motion are shown on a c.r.o. screen and can be photographed.

a rotatory motion is applied to one face of a material a ess will be transmitted, as a torque, through the material. is rotatory motion may be either uniform or oscillatory. the case of a liquid held between two solid plates, the otion is imposed on one plate and a torque (uniform or cillatory) is thereby exerted on the second plate. If the uid is non-Newtonian (visco-elastic), in addition to the rque there is a force, normal to the plates, forcing them art. If the motion applied to the first plate is oscillatory nusoidal) the normal force exerted on the second plate is o sinusoidal, but with a frequency double that of the plied motion (and also, of course, double that of the rque). In general there are phase differences between plied motion, torque and normal force.

When the plates are circular and parallel, the rate of shear an element of the liquid is zero at the centre and increases oportionately to the radius in moving outwards. Since the w properties of non-Newtonian liquids vary with the rate shear it is clearly desirable, in the interests of the inter-etation of the results, that there should be a uniform rate of shear throughout the system. This is achieved by replacing the parallel plates by a cone and plate, the liquid being held in the gap (of very small angle) between the two.

For the measurement of the various effects of stresses applied to visco-elastic materials, the original rheogoniometer of Freeman and Weissenberg[(1)] used optical levers. This method has some disadvantages. Before the response from a system can be studied, a photographic film must be run past the light beams and be developed. If, however, the stresses can be represented by voltage fluctuations in an electric circuit, and the amplified output fed into a cathode-ray oscilloscope, a graph of stress as a function of time can be produced on the screen. This means that adjustments can be made to the rheogoniometer while it is functioning, and a photograph taken when the results are considered to be of value.

The normal way of measuring stress is to allow it to move some part of the instrument; not sufficiently to disturb the experimental conditions, but enough to allow the displacement to be measured. After a review of possible methods, it was decided to detect the movement as an alteration in capacity of a capacitor. It was found possible to detect displacements of less than 10^{-4} cm and either steady or oscillating forces could be measured.

CONE AND PLATE ASSEMBLY

The material under test was held between a cone *A* and plate *B* (Fig. 1). The cone had a semi-vertical angle of 89°, and radius 1·75 in., and was turned from Perspex sheet.

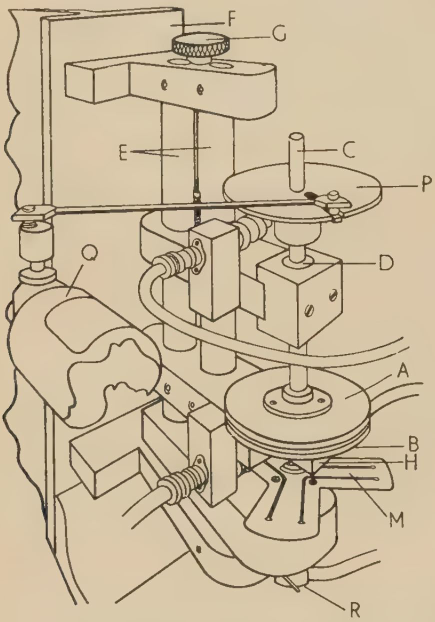

Fig. 1. General arrangement of rheogoniometer

A, cone; *B*, plate; *C*, rod holding cone; *D*, Hoffmann bearings; *E*, guide rods; *F*, girder; *G*, screw adjustment for bearing block; *H*, air bearing; *M*, leaf spring; *P*, aluminium disk for applying oscillatory rotation; *Q*, electric motor; *R*, capacitor for normal thrust measurement.

An alternative cone, made from aluminium, was also used. The plate was also of aluminium. The cone was secured to a silver-steel rod *C* of $\frac{3}{8}$ in. diameter running in a pair of Hoffmann radial bearings *D*. The block which acted as a housing for the bearing was fitted on to two silver-steel guide rods *E*, *E*, $\frac{3}{8}$ in. diameter, which were held on to an I-section girder *F*, mounted on a steel base-plate $\frac{1}{2}$ in. thick. The bearing block could be moved vertically by means of a screw adjustment *G*. A quick release was provided so that the screw only needed to be used for fine adjustments. The bloc could be securely clamped in position with four sock screws bearing on the guides.

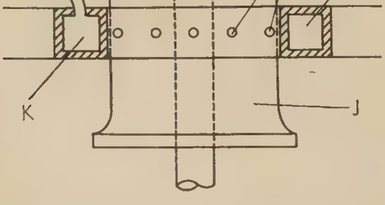

Fig. 2. Air bearing

J, boss on shaft; *K*, annular air chamber; *L*, 12 holes around air chamber.

The plate was also joined to a rod of $\frac{3}{8}$ in. diameter. Th lower end of the rod was sharply pointed and rested in sapphire cup on the surface of the diaphragm of a specia parallel plate capacitor. The rod was located at its uppe end by an air-bearing *H*, the details of which are shown i Fig. 2. In addition to being almost ideally friction-free t rotation, this permitted axial movement. The air-bearing similar to that of Oldroyd, Strawbridge and Toms,(2) was i two parts, one a cylindrical boss *J* on the shaft and the othe an annular air chamber of square section *K*. Twelve radia holes *L* of 0·08 cm diameter were spaced symmetricall around the inside of the chamber. The gap between th boss and collar was 0·001 in. Air was supplied to the colla at a pressure of about 1 lb/in^2.

The rotation of the plate was prevented by a leaf sprin *M* in Fig. 1, with details shown in Fig. 3, supported on th silver-steel rods screwed into the same bracket which carri the parallel plate capacitor *N*. This bracket was free to slid along the guides and could be clamped in position by mea of four socket screws. The spring easily permitted a sma vertical movement, but, together with the silver-steel support resisted a torque. The resulting rotation was small compare with that of the cone, but could be measured by the capacit method to be described.

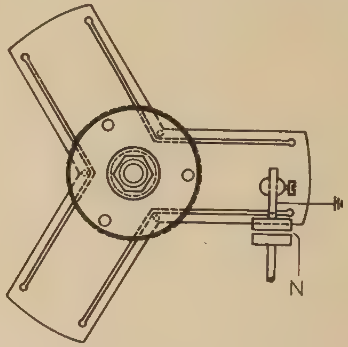

Fig. 3. Leaf spring to resist rotation of plate

N, capacitor.

Two types of motion could easily be imposed. One was continuous rotation of the cone, the other a simple harmoni motion. The former was applied by a geared motor with belt drive to the shaft. For the latter (illustrated in Fig. 1 an aluminium disk *P* at the top of the shaft was connecte by means of a crank to an eccentric on the motor *Q*. Th position of the pivot on the aluminium disk determined th amplitude of motion of the cone, and the frequency wa controlled by a rheostat in the motor circuit.

MEASURING DEVICES

The measurements to be made were those of frequenc amplitude, and position in time of the motion of the con and the magnitude, frequency and position in time both the torque and of the normal thrust experienced by the fla plate. Forces and displacements were measured by mean of the relative movement of a pair of capacitor plates, one which was earthed.

(i) For the applied motion of the cone, the earthed plat was attached to the aluminium disk *P* at the top of the sha ig. 1). The stationary plate was held on the central pole of Belling–Lee socket, firmly secured to the bearing bracket. coaxial cable passed to the phase discriminator No. 1. was found sufficient to use this system merely to indicate frequency and phase of the applied motion, as its ampli-de could be observed directly.

(ii) For the measurement of torque, an earthed plate was stened to the underside of the leaf spring (Fig. 3) and the ed plate attached to the central pole of a Belling–Lee cket on the air-bearing support. A coaxial cable passed the phase discriminator No. 2.

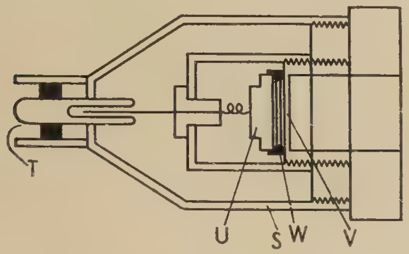

Fig. 4. Gauge for measurement of normal thrust

S, brass outer casing; *T*, socket of coaxial cable connector; *U*, positive plate; *V*, spring diaphragm, negative plate; *W*, polythene insulation.

(iii) For the detection of normal thrust a special gauge ig. 4) was produced which was a modification of those used Lilly, Legallais and Cherry(3) and by Baxter.(4) It differed om their designs in that the diaphragms were interchange-le and there was no hypodermic needle attachment. The sential feature is that if the capacity of the parallel plate pacitor is to be altered appreciably by a very slight move-ent of one of the plates, then the normal separation of the ates must be very small. The outer casing of the gauge was rass cylinder *S* tapered at one end and carrying the socket the coaxial cable connector *T*. The centre pole of the cket was drilled out so that connexion could be made with positive plate *U* by means of a phosphor-bronze spring. spring diaphragm formed the negative or earthed plate *V* the capacitor and this was part of a small cylinder which rewed into the mounting. Small pieces of mica separated plates by about 0·005 in., and a polythene cylinder *W* sulated the positive plate from the casing. A small pressure the diaphragm changed the gap between the plates, and nce the capacity. A coaxial cable connected this capacitor the phase discriminator No. 2. A switch on this dis-minator allowed a rapid change in the connexions from rust to torque observations. Of course, the leaf spring *M* Fig. 1 as well as the diaphragm *V* resisted the vertical rust. But the leaf spring was so designed that its rigidity wards vertical displacements was small. The diaphragm s thus mainly responsible.

The general layout of the measuring devices is represented a block diagram (Fig. 5). The output from each dis-minator was applied to the Y_1 and Y_2 plates of a Cossor uble beam oscilloscope (model 1049). Both discriminators re supplied with h.t., +400 V and −150 V from a bilized power supply, designed by Attree.(5) The dis-minators were similar in design to that of Baxter,(4) except a change in the frequency of the crystal to 1 Mc/s and propriate changes in the circuit components. The principle its action is as follows: if two voltage wave forms, of nearly ual frequency, are applied to the two grids of a mixer valve, the mean current through the valve will depend on their phase relation. The unknown capacitor forms part of a tuned circuit which is suitably driven at its resonant frequency, and the phase can be compared with a known standard frequency provided by a crystal. In the present case the unknown capacitor is any one of the three gauges for measuring thrust, torque or applied motion. The amplified outputs from the two discriminators were fed on to the Y_1 and Y_2 plates of the c.r.o. The deflexion on the screen was linearly related to the original mechanical displacement which gave the change in capacity.

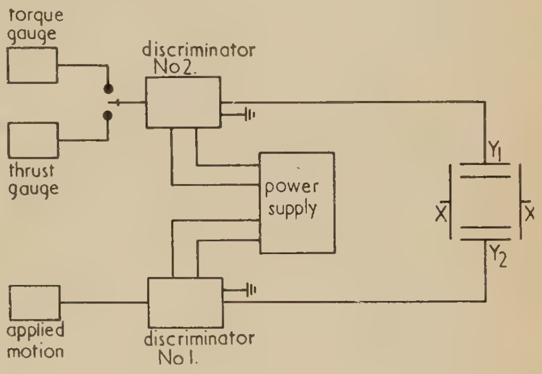

Fig. 5. Block diagram to show layout of measuring devices

The beams could be triggered by an audio-frequency oscillator so that a dotted wave form was obtained. The time interval between the dots equalled the reciprocal of the triggering frequency. This provided a convenient time-scale when the photographs of the wave forms were examined. A 35 mm film, or alternatively a bromide recording paper, was used in the oscilloscope camera, and the traces were measured with a 2-dimensional travelling microscope. In the measurement of thrust, a convenient sensitivity to use gave an output of 0·75 V (corresponding to a deflexion of 2 cm on the c.r.o. screen) for a load of 100 g. The torque sensitivity was about 0·5 V for a torque of 10^6 dyn cm.

Fig. 6 reproduces some typical photographs taken on film in the latest model of the apparatus by Mr. G. M. Jenkins.

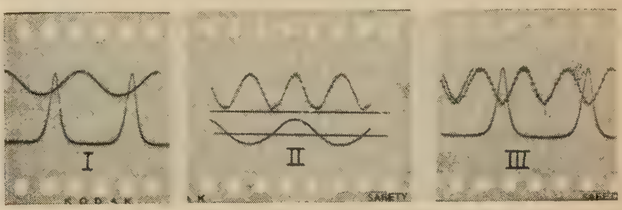

Fig. 6. Photographs of traces on c.r.o.

(i) torque and applied motion, (ii) thrust and torque, (iii) thrust and applied motion.

In (i) the upper curve shows torque and the lower curve applied motion. Although the motion is simple harmonic, the curve is distorted so that the positions of the maxima can be obtained more accurately. Curves in (ii) are thrust and torque, and in (iii) thrust and applied motion. Note the double frequency of the thrust.

EXPERIMENTAL PROCEDURE

The electronic equipment was switched on at least two hours before measurements were made to give time to reach stability. A small quantity of the test liquid was placed between the cone and plate. This part of the apparatus was surrounded by an air thermostat (not shown in Fig. 1). Discriminator No. 2 was set to read normal thrusts and adjusted by means of a variable capacitor in parallel with the gauge so that the output lay on the linear portion of the capacitance-output voltage curve. The cone was carefully lowered into the liquid until a small steady pressure could just be detected as a deflexion of the micro-ammeter needle of the discriminator. The cone was then withdrawn slightly until the deflexion just disappeared, and was clamped in position.

The two traces (corresponding, respectively, to applied motion and normal thrust) were placed in convenient positions on the screen by means of the Y_1 and Y_2 shifts, and the trigger was switched to the internal mains frequency or to the external audio-frequency oscillator. A metronome was set going, with the time between consecutive beats coinciding with the passage of the spot across the screen. The camera was closed and a stationary exposure made. The film or bromide paper was moved through one frame ready for the next exposure. The oscillatory motion of the cone was now started, at its lowest frequency (which was measured with a stop-watch). A photograph was taken of the resulting waveforms. The metronome beat helped in making the exposure at the right time to give one complete trace in the photograph, since the screen was not visible when the camera was closed. This procedure was repeated for several higher frequencies. At high rates of shear, the frequency could be measured directly from the photograph.

The discriminator was now switched to measure torque and similar sets of photographs were obtained, the traces now corresponding to applied motion and to torque. The photographs were developed and the following measurements were made:

(i) The horizontal distance between two consecutive crests on the applied motion curves, in conjunction with an initial calibration, enabled the frequency to be calculated. This could be checked by counting the number of spots between consecutive crests.

(ii) The vertical distance between a crest and trough in th torque curve gave the value of twice the torque ampl tude (converted into absolute units by means of an initi calibration).

(iii) The normal thrust waves had double the frequency o the applied motion. The displacement from the line for zer motion allowed the average normal thrust to be calculate similarly.

(iv) Finally the phase lag between the torque and th applied motion could be measured. This is an importan value in the calculation of the relaxation time of the materia

This apparatus has proved suitable for the study of th rheological properties of polymer solutions and detaile results will be published elsewhere. To test the behaviour o the apparatus, golden syrup was used as an example of very viscous Newtonian liquid. With this, no normal thrus was obtained. The appropriate mathematical theory require in this case that the maximum torque attained shall be pro portional to the amplitude and to the frequency of the applie motion. This was found to be so, and the results led to a average value for the coefficient of viscosity at 25° C o 26·6 poise, compared with a value of 25·3 poise obtaine with a Stokes' viscometer.

ACKNOWLEDGEMENT

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Cooled photoconductive detectors using indium antimonide

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Improvement in the sensitivity of InSb photoconductive cells which operate at room temperature can be achieved under certain conditions by cooling cells to temperatures below ambient. Details of the performance of such cooled cells are given.

INTRODUCTION

e use of InSb in single crystal form as an infra-red detector lizing both the photoconductive(1, 2) and the photo- agnetic effect(3) has been described recently in the literature. ese two types of cell, which operate at room temperature ve comparable sensitivities at any particular wavelength up 6 μ, the peak value of the noise equivalent power* of each ing approximately 10^{-9} W in a one cycle band-width for a l area of 2 mm². If it is assumed that the noise voltage in ese two types of detector is approximately the same, then can be shown(4) that the ratio of signal voltages and hence nsitivities should be approximately unity if recent values of rrier lifetime, mobility,(2) etc., are used.

As the sensitivity of a photoconductive detector is pro- rtional to $(\mu_e + \mu_h)\tau/\sigma$, where μ_e and μ_h are the electron d hole mobilities, τ the carrier lifetime and σ the con- ctivity, then from the known variation of these constants th temperature(2, 5) an increase in sensitivity is to be pected on cooling the cell to below room temperature. e expected variation of sensitivity with temperature for th n and p-type InSb is shown in Fig. 1 assuming that hnson noise is the dominant noise mechanism at all tem- ratures. The two curves have been normalized to give reement with the experimental values of sensitivity at 90° K. e increase in sensitivity on cooling is likely to favour the otoconductive more than the photomagnetic detector provided that the carrier lifetime at any particular temperature is greater than its room temperature value.(4)

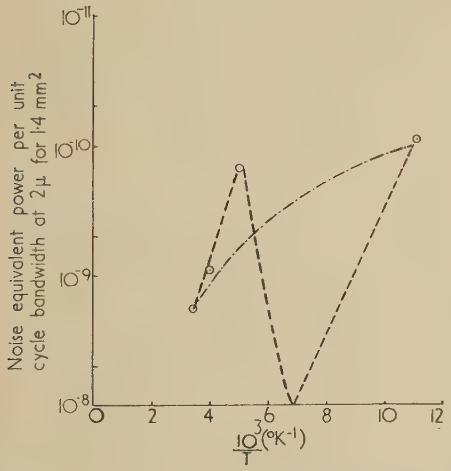

Fig. 1. Variation of n.e.p. of an InSb photoconductive cell with temperature at 2 μ

– – – – Theoretical variation p-type.
–·–·–·– Theoretical variation n-type.

Fig. 1 also indicates that with material currently available, greater sensitivity can be obtained at 200° K using p-type rather than n-type material.

The purpose of this paper is to describe the preparation and properties of photoconducting cells using single crystal material suitable for operation at low temperatures.

PREPARATION OF PHOTOCONDUCTIVE DETECTORS

Thin filaments of single crystal InSb are prepared in exactly the same manner as for room temperature detectors(1) from material usually p-type in the extrinsic region. These filaments have been mounted in double wall Dewar cells similar to those used for PbTe cells.(6) The inner part of the Dewar contains a copper-to-glass seal, the detector being mounted on an insulated plug soldered into the seal. The cells are evacuated to a pressure of 10^{-6} mm of mercury and then sealed-off from the vacuum system.

SENSITIVITY MEASUREMENTS

Absolute measurements of sensitivity have been made at a wavelength of 2 μ using monochromatic radiation from a Leiss double monochromator fitted with fluorite prisms. The radiation is chopped at 800 c/s and the resultant photovoltage after stepping up in a suitable matching transformer is

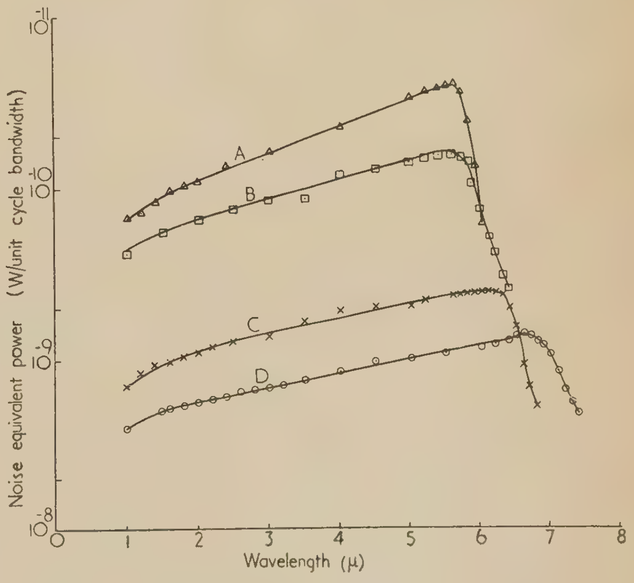

Fig. 2. Spectral response of InSb photoconductive cell, cooled to various temperatures

A, 90° K; *B*, 195° K; *C*, 249 °K and *D*, 292° K.

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* The "noise equivalent power" is here defined as the power cident on the detector in watts necessary to give a signal-to-noise io of one with one cycle bandwidth in the detector amplifier.

Table 1. *Characteristics of coolable InSb cells*

Temperature (° K)	90	19·5	249	292
Cell resistance (Ω)	20 K	1·8 K	490	120
Peak n.e.p. (W/cycle)	$2{\cdot}6\times10^{-11}$	7×10^{-11}	4×10^{-10}	7×10^{-10}
Wavelength of peak sensitivity (μ)	5·6	5·6	6·2	6·7
$\lambda\frac{1}{2}$ (μ)	5·85	6·0	6·65	7·2
Responsivity (V/w)	1300	400	30	1

amplified in a tuned amplifier. Readings of signal-to-noise ratio were made with various voltages applied to the cell in order to determine the optimum operating conditions.

Values of noise equivalent power in one cycle bandwidth with temperature for 2 μ radiation incident are shown in Fig. 1 together with the expected variation for both *n* and *p*-type material. Measurements are given at room temperature, the boiling point of methyl chloride and liquid oxygen and at the temperature of a solid CO_2-acetone mixture. The cell area is 1·4 mm². These measurements indicate that using *p*-type material, the sensitivity of a cell at 195° K approaches that achievable at 90° K.

The spectral response of cells was determined using a conventional monochromator fitted with rock salt prisms, a Nernst filament being used as a source. The power falling on the detector was determined using a Schwarz thermocouple followed by a tuned amplifier. The variation of noise equivalent power with wavelength at different temperatures is shown in Fig. 2. Characteristics of a typical cell are given in Table 1.

Although the wavelength of peak sensitivity decreases by approximately one micron on cooling the cell from room temperature to 90° K, yet the spectral response does extend to slightly longer wavelengths than a PbTe cell.(6) A considerable increase in both cell resistance and responsivity to be noted on cooling.

Measurements of carrier lifetime in InSb(2) suggest tha over this temperature range the lifetime should not excee 4×10^{-7} s.

Estimates of the time constant of cooled cells using pulsed spark source having a decay constant of 2×10^{-7} suggest that it is less than 4×10^{-7} s.

CONCLUSIONS

Provided suitable single crystal InSb is used a considerab increase in sensitivity above that achieved at room temperatu can be obtained by cooling cells to temperatures down to 90° K Although the cell resistance increases on cooling yet its valu makes the cells still suitable for matching into transisto amplifier circuits. The time constant of the cells is less tha 4×10^{-7} s.

ACKNOWLEDGEMENTS

Acknowledgement is made to the Controller H.B.M Stationery Office for permission to publish this paper.

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Laboratory and workshop notes

A valve for the grease-free manipulation of mercury

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[*Note received* 28 *January*, 1957]

precision vapour volumetry it is unsatisfactory to use con- ntional lubricated stop-cocks for the control of mercury w because the motion of the mercury results in the harmful nsference of grease, either by bulk migration or as mole- lar surface films, to the inside of the apparatus. This report scribes the construction and use of a valve system offering solution of this problem. The valve transfers mercury antitatively to or from the working apparatus permitting ntact of the mercury only with Pyrex glass and steel, thus suring absence of lubricant. It is rigid, readily constructed d joined directly to Pyrex apparatus, and with its capillary nnections encloses less than 3 cc. It can be used from the ezing point of mercury (−39° C) to at least 100° C.

Fig. 1(*a*) shows a longitudinal section of the valve. It nsists of a partitioned cylindrical bulb blown from Pyrex bing, containing two steel ball bearings operating on ground rfaces at the extremities of the cylindrical portion, and pable of acting as an absolute stop to mercury flow in the e direction (*R* to *L*), as a slow mercury leak in the other to *R*), or permitting unrestricted flow in either direction.

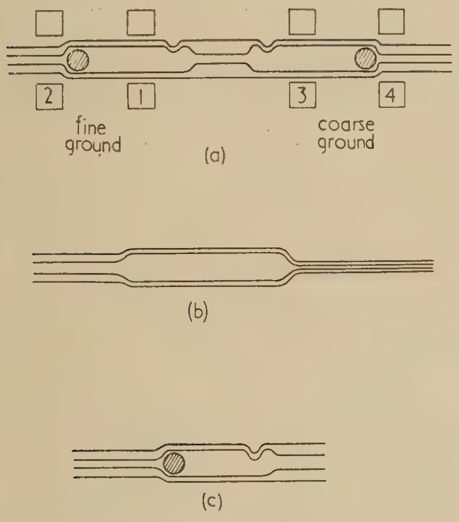


Fig. 1. Details of construction of grease-free valve

Fig. 2 shows a layout suitable for changing the amount of ercury in a working apparatus represented by *A*. The ll bearings are controlled by a powerful circular gap per- nent magnet which can be placed in the four indicated sitions. The working apparatus and the valve com- nicate, by way of a capillary with a finely drawn tip, with e mercury in the detachable weighing vessel *B*. The essure on the mercury surface in *B* can be adjusted within nm of mercury by the air and vacuum controls shown. represents a ballast bulb which simplifies minor adjust- ents of the pressure. The standard joint at *D* is used lubricated. An air filter *E* eliminates any possible grease eep from the external taps. In current usage the apparatus above the dotted line is maintained at constant temperature within 0·01° C, that below within 2° C. The volume of the valve and capillaries is not more than 3 cc so ambient temperature fluctuations do not affect the delivered volume by more than 0·001 cc.

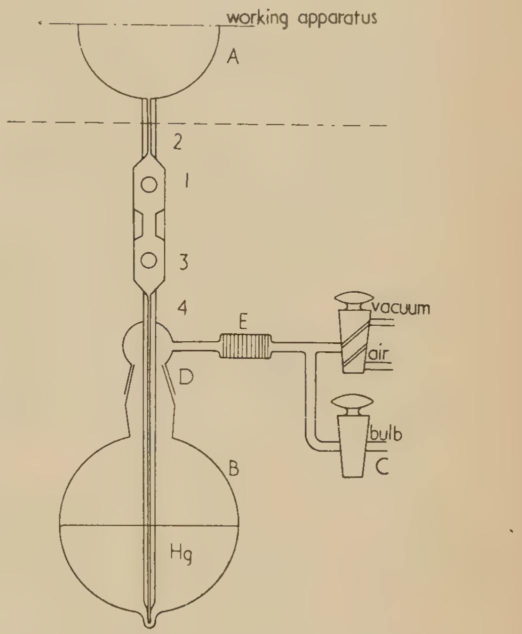


Fig. 2. General layout of grease-free valve

The working apparatus, valve and capillary, are evacuated to 10^{-5} mm of mercury or better for several hours whilst maintaining a rough vacuum in the detachable bulb *B*.

The four positions for the magnet, indicated in Fig. 1(*a*), together with a suitable pressure applied through the detachable bulb, permit one to admit mercury (position 1), to remove mercury in large amounts (position 3), to remove mercury by very slight leakage (position 4) and to provide a permanent positive stop to inward flow (position 2).

Bulb *B* can be detached as required so that the mass of mercury removed or admitted can be determined.

Glass in a length of capillary tubing, 8 mm external, 2 mm internal diameter is gathered and blown into a thick-walled bulb about 25 mm diameter. On re-heating this is drawn out into a cylinder some 11–12 mm external diameter, 1·5 mm wall thickness, 45–55 mm long [see Fig. 1(*b*)]. One end is discarded and the cut fire-polished. Two cylinders are prepared for each final valve.

A seating is prepared by hand grinding a $\frac{1}{4}$ in. steel ball bearing mounted with wax on a glass rod into the capillary-cylinder junction using Aloxite no. 2. The formation of the seating, some $\frac{1}{2}$–1 mm wide on the glass, takes only two or three minutes grinding. Seatings which begin to grind at two or more portions of the circumference and which do not form a continuous area within a few more seconds must be rejected. A close approximation to circular form at all cross-sections of the cylinder-capillary junction is necessary for the formation of a good seating. Every effort must be made to secure this condition: all tubing with evident asymmetry and fault must be rejected; the glass must be gathered, blown and formed under careful control. The position of the ground area does not seem to be critical; seatings subtending 90–120° at the ball centre are satisfactory. When the seating appears well-formed it must be washed with tap water, freed from grinding material with cotton wool swabs and pipe cleaners, and rinsed with distilled water and dried completely. A new grinding ball should be used for each valve seating.

The coarse ends are made similarly using 120 carborundum and without special attention to the form of the seating.

The assembly of the two halves of the valve is the critical operation requiring the greatest attention towards preservation of the polished surface of the ball for the fine ground seating. The surface must not be oxidized nor visibly attacked by corrosive materials from the flame and the hot glass. It is necessary to keep the ball at a temperature near 100° C throughout the remaining stages to prevent condensation of contaminated water vapour on the surface and subsequent chemical attack. Experience indicates that any visible condensation of flame or glass moisture on the ball destroys its sealing property. Fragments of glass must not be allowed to collect inside the working parts. The glass should be cut after a pipe cleaner has been inserted in the capillary, and parts to be joined should not touch until at the softening temperature.

A new ball bearing, rinsed twice in clean benzene and wiped on a clean chamois leather, is inserted into the warmed seating. A temporary join is made at the open end of the cylinder to a piece of capillary as originally used to form the bulb, and the glass of the cylinder remote from the ground end drawn down to a capillary. A small depression is formed in the wall of the cylinder by a carbon tool so that the ball cannot subsequently form an unintentional seating at the non-ground end. The portion is cooled whilst a stream of air is passed through and cut off as in Fig. 1(*c*). The coarse-ground ends are treated similarly.

Finally, the two portions are sealed together using a small hot flame restricted to the central capillary section. During this stage the fine-ground end is held at a considerable angle to the horizontal and with the ball seating on the ground surface. The ball in the coarse-ground end, being held downwards, suffers considerably but as it is designed to leak the damage is of no consequence. A slow stream of pure nitrogen can be passed through the parts during assembly as an additional precaution. The valves cannot be oven-annealed because the balls oxidize, so that the operator must use some care to obtain a well-annealed product. The completed valve should be cooled in a gentle stream of air and stored in a desiccator until required.

The connection of completed valves with the working apparatus should be carried out with precautions to avoid condensation of moisture on the balls as during the manufacture. The valves function vertically with the fine-ground end uppermost and equally well in a horizontal position. It appears detrimental to the valves to use a Tesla leak detecting coil near the ball bearings during the initial evacuation.

The valves on test at one atmosphere pressure remained mercury tight to better than 0·001 cc over several weeks. No deterioration with use has been noted.

Despite the slight possibility that a valve will fail under repeated violent closure by a crack originating at the ground portion, experience indicates that the fragility is no greater than for conventional taps.

Elimination of pen to paper friction in Murday system recordin milliammeters

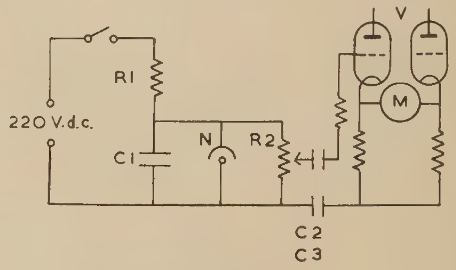
By J. S. Heeks, B.Sc., and D. W. Ovenall, Ph.D., Department of Chemistry, University of Birmingham

[*Note received* 15 *February*, 1957]

One limitation of the Murday type of recording milliammete is its failure to respond to small rapid changes of curren owing to friction between the pen, which is mechanicall operated by the galvanometer, and the recorder chart. Th effect which may cause distortion of signal shapes, has bee studied recently by Tucker.*

We have found that it can be largely eliminated by super imposing on the current being measured, a small alternatin current with a frequency of about 10 c/s. The recorder pe vibrates at this frequency and starting friction is remove It would be most convenient to use a 50 c/s current derive from a mains transformer, but the recorders that have be so far tested will not respond at 50 c/s.

Originally a 12AX7 double triode valve was used as a phas shift oscillator and a cathode follower output stage to provid the 10 c/s current, but the waveform is not critical, and simpler arrangement is the neon oscillator circuit shown i the figure. The output of the oscillator is fed *via* isolatin condensers to one grid of the double cathode follower V which is the final stage of a d.c. amplifier feeding the recorde The 10 c/s current is adjusted so that the width of the recorde trace is doubled by the vibration of the pen. This circuit ha been in use for some months with microwave and electro spin resonance spectrometers, and in both cases it has greatl improved the accuracy of recording. We would like t thank Mr. B. P. Goddard for constructing the circuit.



Neon oscillator circuit

$R_1 = 3{\cdot}7\ \text{M}\Omega$; $R_2 = 2\ \text{M}\Omega$; $C_1 = 0{\cdot}2\ \mu\text{F}$; $C_2, C_3 = 0{\cdot}1\ \mu\text{F}$; N = M.E.S. neon tube (Arcolectric T47); M = 1–0–1 mA recording milliammeter (by Hatfield Instruments Ltd.).

N.B.—The values of R_1 and C_1 may require adjustment for correct oscillation.

* Tucker, M. I. *Electronic Engng*, **23**, p. 61 (1951).

A quenching probe unit for Geiger–Müller tubes

By F. W. Lovick, Department of Physics, University of Birmingham

[*Note first received* 14 *January, and in final form* 12 *Februar* 1957]

Geiger counter circuits usually include a unit, known as th quenching probe, to overcome variations in the dead time o different tubes, and to suppress spurious pulses. Many unit of this type have been described,(1,4) including the Atomi Energy Research Establishment quench probe type 1014,(5 ch is generally useful but lacks a cathode follower output. le capacity therefore reduces the amplitude of the output se from this unit, although it has little effect on pulse pe.

he probe described in this note was developed for use in counting room of the Nuffield Research Laboratory, a large number of such units have been in use for six to n years. In this application simplicity, interchangeability ease of servicing are important requirements, and the sent unit has proved rather more satisfactory than the .R.E. type 1014 in these respects. Since it includes a node follower output stage it has also proved valuable in lications where pulses from a Geiger counter head near a e nuclear machine have to be conveyed to standard ing units a considerable distance away.

he circuit is similar to the type 1014 unit, but omits the node follower drive to the screen and control grid of the valve. This makes the circuit inherently less stable than of the 1014 unit for the same input sensitivity, and the d time is less accurately defined. In practice, however, e disadvantages are not serious if high stability carbon stors are used in the multivibrator circuit, and if the is operated from a scaling unit with stabilized power plies such as the A.E.R.E. type 1009. (In operating from earlier A.E.R.E. type 200 scaler, a ballast resistor is ed to the negative line to maintain the required voltage o of 3 : 1 between positive and negative lines.) Under e conditions the units have shown no tendency to oscillate n adjusted to respond to an input signal of 0·3 V or more. usual setting is for a signal of 0·5 V.

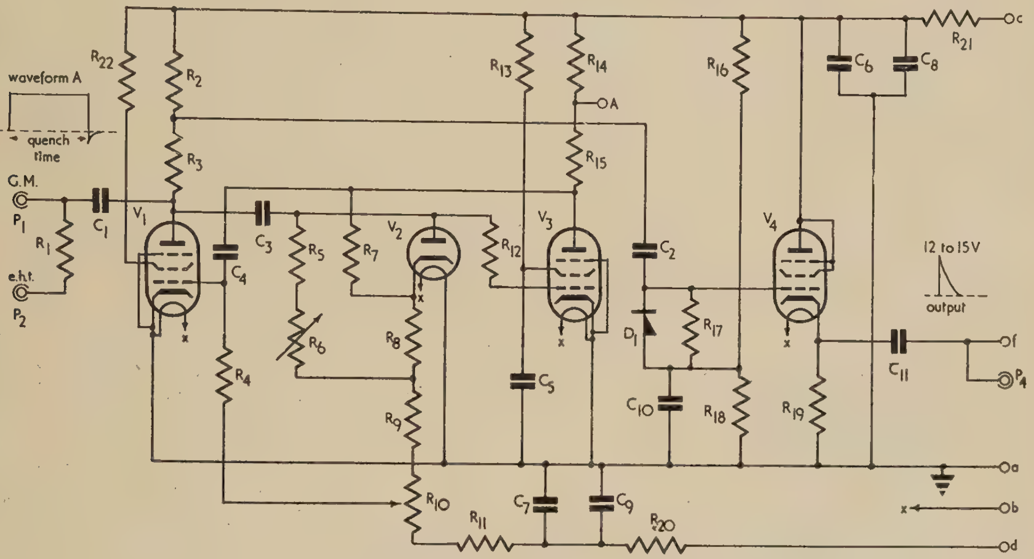
n this Department these probes have been used for the t part with type GM4 tubes, but latterly with Mullard type MX123 tubes, and are normally set to give a dead time of 600 μs. Using a quench time setting of 500 μs the variation due to differences in counter pulse heights appears to be between 25 and 40 μs for the GM4 tube, and between 20 and 30 μs for the MX123 tube.

The unit consists basically of two high-frequency pentode valves V_1 and V_3, coupled in the form of a monostable multivibrator. The resistance chain of R_{7-11}, connected from V_3 anode to the negative line, applies a negative voltage to V_1 grid, and a less negative voltage to V_3 grid through the diode V_2 giving the d.c. conditions for the quiescent state of the unit, with V_1 cut off and V_3 conducting.

A negative pulse from the counter tube, produced across a 10 MΩ resistor from the extra high tension supply to counter anode, is applied through a 3 kV, 0·001 μF capacitor to V_1 anode, and thence to V_3 grid. This reduces the anode current of V_3 and initiates the flip-flop action, the time of which is controlled by C_3 with R_5 and R_6, and which produces a 200 V negative square wave at the anode of V_1 to quench or suppress the counter tube for the duration of a pulse.

At the end of a pulse, as the multivibrator returns to its quiescent state, part of the falling voltage of V_3 anode is applied to its grid by the feedback circuit of R_7 and V_2. This has a stabilizing effect on the gain of V_3 and also reduces the large overshoot which would otherwise appear at the end of the pulse on V_3 anode, and consequently renders the circuit insensitive to a second counter pulse for longer than the apparent quench time.

Part of the negative waveform from the junction of R_2 and R_3 is applied through the differentiating circuit of C_2 and R_{17} to the grid of V_4. The negative pulse is clipped by the crystal diode D_1, and V_4 working as a cathode follower gives a



Circuit diagram of quenching probe unit

Resistor and capacitor table

R_1 = 10 MΩ ½ W grade II
R_2 = 12 kΩ, ½ W grade I
R_3 = 47 kΩ, 1 W grade I
R_4 = 560 kΩ. ¼ W grade II
R_5 = 5 MΩ, ½ W grade I
R_6 = 5 MΩ, carbon potentiometer
R_7 = 390 kΩ, ½ W grade I
R_8 = 15 kΩ, ½ W grade I
R_9 = 33 kΩ, ½ W, grade I
R_{10} = 100 kΩ, carbon potentiometer
R_{11} = 270 kΩ, ½ W grade I

R_{12} = 1 kΩ, ¼ W grade II
R_{13} = 220 kΩ, ½ W grade II
R_{14} = 3·3 kΩ, ½ W grade I
R_{15} = 56 kΩ, 1 W grade I
R_{16} = 750 kΩ, ½ W grade II
R_{17} = 150 kΩ, ¼ W grade II
R_{18} = 47 kΩ, ¼ W grade II
R_{19} = 4·7 kΩ, ½ W grade II
$R_{20, 21}$ = 1 kΩ, ½ W grade II
R_{22} = 220 kΩ, ½ W, grade II

C_1 = 0·001 μF mica, 3 KV
C_2 = 68 pF ceramic, 350 V
C_3 = 50 pF mica, 350 V
C_4 = 12 pF mica, 350 V
$C_{5, 6, 7}$ = 8 μF electrolytic, 350 V
$C_{8, 9}$ = 0·001 μF mica, 350 V
$C_{10, 11}$ = 0·1 μF paper, 350 V

V_1 = CV 138
V_2 = CV 1 092
V_3, V_4 = CV 138

D_1 = CV 425

$P_{1, 2}$ = MK IV, Plessey concentric plug
P_3 = MK IV, Plessey 6-way plug (pins *a*, *b*, *c*, *d* and *f*)
P_4 = Belling and Lee concentric sockets L 604/S

12 to 15 V positive pulse to the scaler input. The grid of V_4 is set at a positive potential, to allow a negative output pulse to be used, by reversing the diode D_1.

The power supplies to the unit are +285 to +315 V h.t. at 10–11 mA, and −95 to −105 V at 0·4 mA for the negative line. The ratio of positive to negative voltage should be 3 : 1, and the unit is usually operated from the power supplies of A.E.R.E. type 200 or 1009 scaling units.

A 0·5 V negative pulse is applied to the input from a pulse generator (test set type 219 or similar unit) through a 100 pF capacitor. This prevents the low impedance output of the pulse generator decreasing the pulse height at V_1 anode. The 100 kΩ carbon potentiometer is then adjusted until the circuit just triggers.

The 3·3 kΩ resistor in the anode circuit of V_3 is used as a "looking" point for the oscilloscope lead, and the length of the square wave (waveform "A" in figure) can then be adjusted by the 5 MΩ potentiometer R_6 for the required quenching time.

Owing to the high sensitivity of the unit, it is important that anode and grid leads should be kept reasonably short, and that the anode resistors of V_1 and V_3 should be kept well apart. All resistors connected with the multivibrator circuit must be high stability carbon types, as indicated in the figure.

REFERENCES

(1) NEHER and HARPER. *Phys. Rev.*, **49**, p. 940 (1936).

(2) LIBBY, LEE and RUBEN. *Rev. Sci. Instrum.*, **8**, p. 38 (1937).

(3) GETTING. *Phys. Rev.*, **53**, p. 103 (1938).

(4) MAIER–LEIBITZ. *Rev. Sci. Instrum.*, p. 500 (1948).

(5) COOKE-YARBOROUGH, FLORIDA and DAVEY. *J. Sci. Instrum.*, **26**, p. 124 (1949).

A graphical method for the correction of counting rates for dead time

By Y. W. CHAN, B.Sc., Physics Department, University of Hong Kong

[*Note received* 1 *April*, 1957]

The observed number of events detected per second by a Geiger counter depends on the dead time, the number of events n which would be detected per second if the dead time was zero being related to the actual number m and the dea time τ by the equation

$$n = m/(1 - m\tau)$$

When dealing with a large number of observations it sometimes convenient and less laborious to use a simp graphical method of finding n from the known values of and τ instead of finding n by direct substitution.

For a given value of τ, the quantity $m/n = 1 - mT$ plotted against m, yielding a straight line as shown in th figure. The point P, corresponding to an observed countin rate m', is marked on this line. With the aid of a Perspe ruler, the point where OP cuts the horizontal line $m/n =$ is determined; the m co-ordinate of this point is $m'/(1 - m'$ which is the required corrected counting rate.

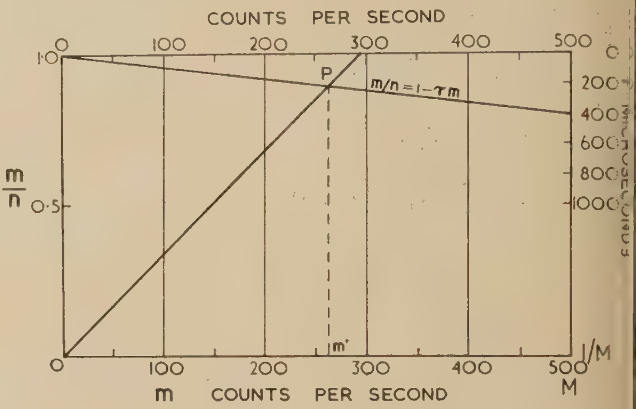


Diagram showing graphical method

In order to plot m/n against m for a given value of τ, it convenient to mark the right-hand side of the graph in unit of τ. The scale of τ is linear and extends from $\tau = 0$ $\tau = 1/M$ where M is the abscissa corresponding to the righ hand end of the m scale.

REFERENCES

(1) ANDREWS, HOWARD L. *Rev. Sci. Instrum.*, **21**, p. 19 (1950).

(2) BLENLER, E., and GOLDSMITH, G. J. *Experimenta Nucleonics*, p. 57 (New York: Reinhart and Co. Inc 1952).

New instruments, materials and tools

Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved ducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

tage stabilizers. Philips Electrical Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

ange of a.c. voltage stabilizers with outputs from 1 to VA is now available. The output voltage is controlled a transductor in series with part of the main transformer ding, any slight variation in secondary voltage being inated by a bridge circuit and amplifier. A safety relay omatically reduces the secondary voltage if this rises above ertain level. It is stated that the stabilizers are relatively nsitive to changes of frequency or inductive power factor. good sinusoidal output is ensured by the use of filters. iations in the mains voltage from −15% to +10% and ±3% in frequency are permissible for an output within ·2% of the nominal voltage. For the 1·5 kVA model, ns voltage fluctuations can be from −30% to +10%. stabilizers are fully tropicalized and the larger types are ised in lacquered steel cases on the front of which are unted a mains switch, input and control circuit fuses, meter, ammeter, pilot lamp and an adjustment for setting output voltage.

h-sensitivity relay. Assembly Products Inc., P.O. Box XX, Palm Springs, California, U.S.A.

model 126 relay has a moving-coil armature which can ate in the flux gap of an Alnico magnet. The moving nent has jewel bearings, and is similar in general con- iction to that of a voltmeter or microammeter. The nter of the ordinary meter movement is replaced by a inum–iridium contact. A locking coil in the moving nent develops additional torque to drive the contacts ether with considerable pressure. The contacts are mally rated at from 5 to 25 mA d.c., depending on the que provided by the locking coil. Auxiliary contacts ated by the latter will handle ½ A at 125 V a.c. The rument can be supplied to operate on a.c. or d.c. in rent ranges from 50 μA to 10 A and voltage ranges from nV to 500 V, the accuracy of the operating current being . Instruments of reduced accuracy operating at 0·2 μA kΩ) or 0·1 mV (5 Ω) are also available. The device, ch is contained in a sealed metal case measuring only 1¼ × 2¼ in., fits a 9-pin miniature socket; it can, if uired, be supplied with fixing screws and solder terminals.

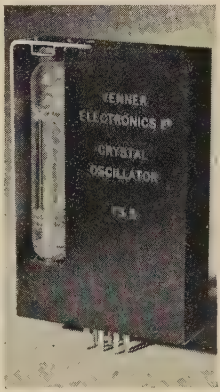
nning thread illuminator. Meiner's Optical Devices Ltd., 121 London Wall, London, E.C.2.

s instrument, for illuminating all types of spinning and sting frames employed in the cotton, wool, staple fibre, n and other textile industries, consists of a single lamp connected by square section tubes to reflector heads d with mirrors and lenses, through which beams of light projected to illuminate the threads along the whole length both sides of a spinning frame. The horizontal beam of it is projected from one end of the machine to the other, ve the spindles, eliminating all dazzle. he beam, about 3½ in. in diameter, brings out the running eads in bold relief, making possible the immediate detection gaps caused by broken ends. Fine white or coloured eads become visible when viewed down the length of the machine since the light beam illuminates only the threads and not the structure of the machine. The intensity of light along the beam is said to be evenly maintained from first to last spindle by the use of reflecting mirrors fitted at the opposite end of the frame. The thread illuminator requires no maintenance other than the occasional replacement of the special mercury vapour lamp.

Transistor crystal oscillator. Venner Electronics Ltd., Kingston By-pass, New Malden, Surrey.

The packaged oscillator illustrated in the figure provides two outputs, a sine and a square wave, at a frequency of 10 kc/s. An *XY* flexure quartz crystal is used to provide accurate control, a preset capacitor being used external to the block to set the oscillator to the exact frequency. The circuit is encapsulated in synthetic resin with the exception of the crystal, which is replaceable.

The oscillator may be used with two types of crystal, one having a zero temperature coefficient between 15 and 20° C so that maximum accuracy is obtained at room temperature, and the other a zero temperature coefficient between 40 and 50° C for applications where the ambient temperature is of this order. The stability of the oscillator at or about the point where the zero temperature coefficient occurs is of the order of 3 parts in 10^6.



Transistor crystal oscillator encapsulated in synthetic resin

The supply voltage is nominally 10 V, but the stage will operate satisfactorily with supplies from 12 to 4 V. The square wave output is approximately 7·5 V peak-to-peak with a 10 V supply; the sine wave output is about 5·6 V for the same supply. A low impedance output is provided for the square wave through an emitter follower, and provision is made for gating.

The unit is suitable for supplying the transistor decade counter and scaler type TS10* and the binary unit type TS2, from which many types of frequency and time-reference, time delay and time-measuring devices can be constructed.

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* *J. Sci. Instrum.*, 33, p. 509 (1956).

New books

Determination of moisture in solids. By P. J. Geary. (Chislehurst: British Scientific Instrument Research Association, 1956.) Pp. iv + 51. Price 7*s.* 6*d.*

This is a list of references to literature, methods, and commercial apparatus, classified according to the type of method. Besides a five-page general introduction, there are short critical introductions at the head of each of the ten sections and twenty-four sub-sections. Where the title of a reference is not sufficiently explanatory, a few words are added as may be necessary. The addresses of the makers of commercial apparatus are given, with brief particulars where these are not obvious from the text.

The classification is systematic, and a great deal of useful information has been brought together. It would be too much to expect completeness where the subject is spread through so many types of literature, and perhaps most specialists would detect omissions from their own branch of work; certainly the reviewer feels that papers originating from the textile industry have received too little notice. This is but a small criticism, however, and the author deserves our thanks for a useful and much-needed piece of work.

P. S. H. Henry

Instrument technology. Vol. II. Analysis Instruments. By E. B. Jones. (London: Butterworth's Scientific Publications Ltd., 1956.) Pp. xi + 208. Price 40*s.*

The book is intended to cover part of the instrument maintenance syllabus of the City and Guilds examination, but it should be valuable to all who are concerned with the maintenance or use of instruments for automatic chemical analysis.

The author does well to begin with a chapter on sampling systems for gases and liquids as these are too often neglected. The following chapters describe instruments for measuring various particular physical properties of liquids and gases with the object of recording or measuring chemical composition. With a few exceptions all commercially available British instruments are described. Each section begins with a short introduction outlining the theory of the method and individual instruments are then described in detail.

The expositions are, on the whole, admirably clear and supported by excellent diagrams, but the book leaves the impression that too much has been attempted and that the same information could be obtained from manufacturers' catalogues. While the author cannot be expected to make direct comparisons of instruments of different makes, there is a marked lack of critical appraisal of the utility or of the accuracy of the instruments described which lessens considerably the value of the book to the prospective instrument user.

G. Jessop

Modern methods of microscopy. Edited by A. E. J. Vickers. (London: Butterworth's Scientific Publications; New York: Interscience Publishers Inc., 1956.) Pp. iii + 114. Price 15*s.*

This collection of articles, from *Research*, usefully surveys the active field of its subject including optical, electron and X-ray microscopy, with emphasis on the optical side. saying that there is no mention of the proton microscop nor of the use of circularly polarized light in optical micr scopy, the reviewer is confessing that he has found r omissions of consequence.

The levels, both of writing and of prior knowledge assum in the reader by the various authors, are inevitably somewh variable and too many minor obscurities and errors have be allowed to pass. Thus on page 16 "$\phi \propto (\text{N.A.})^8$" does n make it clear whether the 8 is a power index or a referen to literature, while on page 58 "2μ" is equated to "40 μin

References to literature are adequate, though the examp of some contributors in giving a "Bibliography" separate from "References" might usefully have been followed l others.

D. G. Drummond

U.H.F. tubes for communication and measuring equipme By members of Philips electron tube division (Electro tube series, Book XI) (Holland: Philips Techni Library, 1957). Pp. vii + 60. Price 9*s.* 6*d.*

The addition of general information, some notes on circ design and hints on construction make this compilation data into something more than a mere catalogue, thoug large part is formed of characteristics and curves. The da applies, obviously, to valves manufactured by the Phi Company. Standard noise sources are also included.

A. J. Maddock

Temperaturstrahlung. By W. Pepperhoff. (Darmsta Verlag D. Steinkopff, 1956.) Pp. xi + 279. Pri DM 39.50.

The present volume of the *Forschungsberichte* gives a fai comprehensive survey of the main aspects of thermal radi tion. The subject is subdivided into three parts deali respectively with the radiation laws, the infra-red properti of matter and the fields of application.

In the first section the laws of black body radiation a stated and illustrated by diagrams. The practical realizati of a black body is discussed and the section is supplement by Planck's formula in tabulated form at the end of the boo The radiation properties discussed in the second section a those of gases, metals, various other solids and of disper systems, such as colloids and droplet suspensions. In th section the reader will find a useful discussion of the optic properties of metals and a considerable number of grap giving emission and absorption of different substances. Th third section deals in turn with various forms of radiati measurement, with pyrometry and with problems of ener transport by radiation. Here, as in the rest of the volum the emphasis is placed on practical applications.

The survey will form a useful guide for the non-speciali physicist and for those working in other fields of science a engineering looking for general information on therm radiation. A fairly extensive list of references to origin work is provided.

K. Mendelssohn

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

aboratory glassware and thermometers. H. J. Elliott Ltd., fil Works, Treforest Industrial Estate, Pontypridd, morgan. A price list and supplement No. 1 for catalogue 7 (1st, 2nd and 3rd editions) has been issued. This plement gives full details of the new laboratory glassware thermometers manufactured by this firm.

ignal Generator. Airmec Ltd., High Wycombe, Bucks, flet No. 169 describes the standard signal generator e 201) which will provide accurate, sinusoidal signals of e wave form from 30 kc/s to 30 Mc/s.

hermometers. The Emil Greiner Co., 20–26 N. Moore et, New York, U.S.A. A 12-page illustrated booklet ains details of many instruments including an electronic stance thermometer which covers a range from −100° C 00° C, a sensitivity of 0·01° C and direct digital reading emperature.

emiconductor data. Mullard Ltd., Mullard House, rington Place, London, W.C.1. A new booklet contains plete information—including characteristics, curves and lications notes—on the entire range of Mullard germanium les and transistors. Additional data sheets can be inserted ne booklet.

luorimeter. Mount Sopris Instrument Corporation,) Pearl Street, Boulder, California, U.S.A. A leaflet gives ils of a fluorimeter which employs a sensitive multiplier totube to detect the characteristic fluorescence of uranium pounds in what the manufacturers claim as a rapid, rate, and reliable method of assaying.

periodic balance. Griffin and George Ltd., Ealing Road, erton, Wembley, Middlesex. A pamphlet (P.1924/5610) s details of the Nivoc automatic aperiodic balance. A ial feature is that the balances are fitted with a special -release mechanism which ensures low velocity contact veen knife edges and planes even when the balance is ised.

ocking table. Short Brothers and Harland Ltd., Queen's nd, Belfast. A brochure describes a rocking table which servo-controlled two-axis unit that has been evolved for elopment work and functional testing of gyro controlled ems.

tock panel instruments. Simpson Electric Company,) West Kinzie Street, Chicago 44, Illinois, U.S.A. A new ge bulletin (2057) has just been released. It contains riptions and specifications with latest prices of stock el instruments.

scillator. Airmec Ltd., High Wycombe, Bucks. Leaflet 162 gives details of the standard oscillator (type 213) ch is a compact frequency standard providing 100 kc/s 1 Mc/s signals of high accuracy and stability.

ensitive relay. Electrical Remote Control Co., Ltd., and 15 Avanston Avenue, Highams Park, London, E.4. No. 52 describes a sensitive Swedish iron relay (Type V).

il meter. George Kent Ltd., Luton, Bedfordshire. lication No. 227 gives details of a low-flow oil meter, suitable for many industrial applications, including the quantitive measurement of fuel consumed by small oil-fired furnaces.

Transverse profiler. Baldwin Instrument Co., Ltd., Dartford, Kent. A leaflet No. 127 has been issued describing the "Atomat" transverse profiler which provides immediate level measurement for the paper, paper-board and plastic industries.

Resistance capacitance comparison bridge. Nash and Thompson Ltd., Oakcroft Road, Chessington, Surrey. A leaflet describes a new resistance capacitance bridge which is intended for the measurement of resistance and capacitance or for the comparison of resistors, capacitors or inductors against known standards.

Flying-spot particle resolver. Cinema Television Ltd., Worsley Bridge Road, London, S.E.26. A 6-page leaflet describes a flying-spot particle resolver which has been designed to overcome a number of the disadvantages inherent in conventional microscopy and is also capable of automatically counting and sizing microscopic particles.

Recording oscillograph. Seismic Instruments Ltd., Granta Works, Cambridge. A 4-page illustrated leaflet describes the BER 62 recording oscillograph which has been designed primarily for Seismic exploration. It has, however, applications in many fields of research and records signals varying from d.c. to 100 c/s photographically on 25 independent traces. Time marking lines appear across the record every ten milliseconds, every fifth line being heavy as an aid in computing.

Seismic detectors. Electro-Technical Laboratories, Inc., 504 Waugh Drive, Houston, Texas, U.S.A. A 12-page illustrated catalogue, entitled "Electro-Tech," gives details of a range of Seismic detectors and accessories.

Single pan balance. Stanton Instruments Ltd., 119 Oxford Street, London, W.1. An illustrated folder describes an automatic single-pan balance which has full external weight loading up to 200 g.

Transformers. The Zenith Electric Company Ltd., London, N.W.2. A 15-page catalogue describes the range of Variac regulating transformers. The catalogue indicates many new sizes and types including a range of special Variacs for operation in high periodicity circuits.

Handling tools and devices. Savage and Parsons Ltd., Watford, Hertfordshire. Publication number 7/1 describes a range of remote handling equipment for radio-active and toxic materials. The equipment includes two types of tong assemblies, with various tong heads and jaws each designed for particular operations, and other devices including scissor and filter attachments; tools for handling and opening isotope containers; pipette operating heads, and a device for holding and sealing glass ampoules after they have been filled with active substances or liquids.

Electronic equipment. Cinema Television Ltd., Worsley Bridge Road, London, S.E.26. An 8-page illustrated catalogue describes part of a wide range of electronic equipment including automatic frequency monitors, oscilloscopes, electronic recorders, and television equipment.

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

Fellows: F. Berz, E. L. Deacon, J. L. Farrands, F. Fowweather, R. G. Gosling, F. W. Hayward, W. E. Lamb, E. Stanley, H. Tipton, S. A. Young.

Associates: F. G. Blackler, D. G. Blears, A. C. Causon, J. C. Frame, A. Gerrard, T. P. Gray, A. Bose, S. M. Hamberger, B. V. Hamon, C. J. Hunt, T. W. Johnson, B. W. Leake, J. G. W. Lee, I. W. McLean, I. H. Mahadeva, H. F. W. Mander, E. H. B. Martin, A. W. Matz, E. H. Medlin, J. S. Morgan, J. D. Stuart, M. E. J. West, J. E. Wright, F. R. Young.

Fourteen Graduates and eighteen Students were also elected.

Conference on peaceful uses of atomic energy

The British Government have accepted an invitation from the Secretary-General of the United Nations to participate in a second International Conference on the peaceful uses of atomic energy, to be held in Geneva in 1958 from 1 September to 13 September inclusive. The last Conference, in 1955, occurred at a time when a great deal of work previously classified by the U.K., America and Canada was released for publication, and the same will be true of the next one since further important fields of work have recently been declassified.

A provisional topical agenda has been agreed by the seven-nation Advisory Committee, of which Sir John Cockcroft is the United Kingdom member, providing for 12 plenary sessions embodying papers of a general survey type, and four parallel series of technical sessions (68 3-hour sessions in all).

The technical sessions cover the following subjects:

Series 1: Chemistry and the chemical processing of irradiated fuel; reactor technology; radiation damage in reactor materials; handling of highly irradiated materials; treatment of radioactive wastes.

Series 2: Nuclear physics, including the physics of fission and fusion reactors; reactor theory; fuel cycles and the economics of nuclear power; research test and prototype power reactors; reactor experiments.

Series 3: Production and uses of isotopes and ionizing radiations in research, medicine, agriculture and industry; dosimetry; biological effects of radiation; radiological protection; reactor safety and location; meteorological and oceanographical aspects of the large-scale use of atomic energy.

Series 4: Raw material supplies; winning and refining of uranium and thorium; methods of separation of isotopes; metallurgy and fabrication of fuel elements; processing of other nuclear materials.

The conference will be conducted under the same rules of procedure as in 1955, which are published as Annex I
Volume 16 of the "Proceedings of the International C
ference on the peaceful uses of atomic energy". Officials
the Conference, namely, the President, Vice-Presiden
Secretary-General, Deputy Secretary-General, Chairmen
Vice-Chairmen of the technical sessions will be announ
later.

Arrangements for United Kingdom participation are be
organized through an Executive Committee (Chairm
Sir John Cockcroft; Secretary, Mr. B. W. Mott), and a Pape
Committee (Chairman, Dr. B. F. J. Schonland; Secreta
Dr. T. A. Hall), on which are representatives of the Uni
Kingdom Atomic Energy Authority, the Central Electric
Authority, Industry, Universities and other bodies. Ti
and 500-word abstracts of papers must be in the hands of
Secretary-General of the United Nations by 1 March, 19
and final texts by 1 June, 1958. At present the Papers C
mittee is engaged on the compilation of a provisional lis
titles, with the object of ascertaining the approximate
number likely to be submitted by the United Kingdom
the distribution between the various sessions. It is ho
that this information will be available by 1 September, 1
Organizations represented on the Papers Committee wi
approached by their representatives for contributions,
others are invited to communicate directly with the Pa
Secretary, at the Atomic Energy Research Establishm
Harwell, Berkshire, if they have titles to submit or if
seek further information. Enquiries concerning ma
other than the submission of papers should be addresse
the Secretary of the Executive Committee, at the same add

British Journal of Applied Physics

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New books

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SPECIAL ARTICLE

Physics and the new electronics*

By R. A. Smith, M.A., Ph.D., Royal Radar Research Establishment, Malvern, Worcs.

A comparison is made of vacuum electronics and the new electronics using crystalline solids. The very stringent requirements as regards chemical purity and structural perfection of the crystals are discussed. Some experiments which have been made possible through the availability of such high purity crystals are described, including some recent work on semiconductors. A brief account of atomic amplifiers using paramagnetic crystals is also given. The effect of these new developments in the application of the physics of solids on the training of electronic engineers is discussed.

VACUUM ELECTRONICS

ctronics has become, in recent years, a very wide subject ı many ramifications. For the present purpose the term estricted to the study of "free" electrons and of devices ed on their use. In the course of this article it will become r what is meant by free electrons. Originally, the term rred to electrons separated from bulk matter and moving high vacuum. J. J. Thomson's discovery of such free trons(1) in 1897 opened the subject of electronics as well aving a profound influence on all modern physics. Until 8 the only kind of free electron that had been envisaged one travelling in a good vacuum so that it had very little nce of colliding with a gas molecule, in traversing the el containing the vacuum.

uppose we have a partial vacuum corresponding to a ssure of 10^{-3} mm of mercury or approximately 10^{-6} osphere. The number of molecules per cubic centimetre N.T.P. is approximately 3×10^{19}, so we should still have ut 3×10^{13} molecules per cubic centimetre. Now the n free path l for a collision is of the order of $(NA)^{-1}$, re A is the equivalent collision cross-section of a molecule N is the number of molecules per unit volume. (This is the thickness of gas which would be required to produce tal area of molecular cross-sections equal to unity, i.e. that $lNA = 1$.) If we take as a representative figure $= 10^{-15}$ cm^2 we see that for a pressure of 10^{-3} mm of cury l is of the order of 30 cm. The chances of making a ision in moving a distance of the order of 1 cm is therefore e small. In practice it is found necessary to use even r pressures than this in electronic devices such as mionic valves. The reason is that only a few collisions produce adverse secondary effects, such as ionization, pressures of the order of 10^{-6} mm of mercury are used, esponding to a residual concentration of molecules of order of 3×10^{10} cm^{-3}.

CRYSTALLINE-SOLID ELECTRONICS

n electron moving through a solid on the other hand, until recently, thought of as colliding continually with atoms of the solid, and it was assumed that electrical tance arose from this cause. Now, for a solid, N is of order of 10^{23} cm^{-3} so that the mean free path l would bout 10^{-8} cm, or of the order of the distance between the ıs. It was shown theoretically, however, by F. Bloch(2) in 1928, using wave-mechanics, that, in a perfect crystalline solid, an electron may move unimpeded by the atoms of the solid and so may also be regarded as "free." It is with this kind of "free" electron that the new electronics is concerned. These electrons certainly make collisions with impurities and imperfections in the crystal structure, and these play an analogous part to the residual molecules in a vacuum. Such collisions contribute to the electrical resistance. The rest of the electrical resistance comes from departures from a perfect crystalline lattice owing to thermal agitation.

If we assume that the effective collision cross-section has the same order of magnitude as before, we see that an impurity concentration of 3×10^{13} cm^{-3} will give a mean free path of 30 cm. A concentration 10^{16} cm^{-3} will reduce this to about 1 mm. This concentration indicates that for the electrons in a crystal to be regarded as free over distances of the order of a few millimetres, very pure and perfect crystals are required, a concentration of 10^{16} cm^{-3} corresponding to an impurity content of about one part in ten million. As for vacuum electronics, secondary effects make even concentrations of this order of certain types of impurities intolerable. For example, in germanium and silicon used for modern electronic devices, uncontrolled impurity concentrations of elements from the neighbouring columns of the periodic table of much more than one part in 10^{10} are undesirable.

The usefulness of free electrons to make possible devices such as the thermionic valve depends on three main factors; (i) having a convenient source of free electrons, (ii) having a good vacuum into which to inject them, (iii) having a convenient and *very rapid* control of the numbers injected. The source most commonly used is the hot cathode and it must be admitted that this is one of the most unsatisfactory and troublesome features even of modern thermionic valves. Progress depended on the development of suitable cathodes and also on the development of techniques for the production, and retention over long periods, of high vacua. The rapid control mechanism was supplied by the invention of triode action by Lee de Forest in 1907.(3) For the use of free electrons in solids a much longer time elapsed between the initial proposal of Bloch, that electrons in nearly perfect crystals should be regarded as free, and the full exploitation of this idea in practical devices. This was, to a very large extent, due to the difficulty in obtaining sufficiently pure and perfect crystals of suitable material. This problem of purification has only been solved in the past ten years. It is physical rather than chemical processes to which this success must be attributed and this is by no means one of the least important contributions of physics to the new electronics.

Based on a lecture delivered before the London and Home ıties branch of The Institute of Physics on 20 March, 1957.

Moreover, it has had a marked reaction in advancing the fundamental physics of solids. The problems of injection and control were solved more or less simultaneously with the discovery of transistor action in semiconductors by Bardeen, Brattain and Shockley(4, 5) in 1948, a discovery for which they were jointly awarded the Nobel Physics Prize in 1956. This discovery had been preceded by a great deal of research in a number of laboratories on the properties of semiconductors, and in particular by an appreciation of the importance of the fact that there are two types of current carriers in semiconductors, electrons and positive holes, one or other generally predominating in numbers but not necessarily in importance. It is, in fact, the minority carriers that may be injected at will and controlled in transistor action.

It is not proposed to discuss in detail in this article the great variety of devices such as the point-contact and junction transistors, various forms of diode, photo-diodes, phototransistors, radiation power generators, etc., that have been developed in the last few years as these have been dealt with extensively in many recent publications (see, for example, Ref. 6). Instead it is proposed to discuss some of the problems in physics that are still having to be faced in the development of such devices, and at the same time to try to appreciate the enormous impact on the physics of solids which this work has had. It is also proposed to mention some less familiar devices which have been developed in the process of recent research.

PROBLEMS OF PURIFICATION

The purity required in semiconductors in order that their electrical properties may be under control is, as we have seen, very high indeed. The current carriers in perfectly pure germanium at 300° K consist of about $2 \cdot 5 \times 10^{13}$ cm^{-3} each of electrons and positive holes. If we were to add a concentration of 10^{14} cm^{-3} of donor impurities, such as arsenic atoms, this would have a marked effect on the conductivity, each donor atom contributing an electron which would act as a current carrier. Yet this corresponds to a concentration of only about one part in 10^9! The most powerful method of purification to this high order is that of zone refining, applied to semiconductors first by W. G. Pfann.(7) This removes most of the troublesome impurities from germanium. For silicon, however, boron has proved to be very difficult to remove, since its solubility in molten silicon is almost exactly the same as in solid silicon, and the zone refining process depends on there being an appreciable difference between the two. This problem has now also largely been solved, one method being to remove all traces of boron first by chemical methods. Such methods are generally not in favour for this kind of work as they introduce many other impurities. However, as these may generally be removed by subsequent zone refining, pure silicon may eventually be obtained.

Chemical purity is unfortunately not the only requirement. Single crystals of a very high order of structural perfection are required. In the process of growing such crystals, usually by pulling from a melt by means of a seed crystal, other impurities may be introduced. This is particularly so in the case of silicon with its high reactivity when molten. There is indeed no known crucible material with which molten silicon does not react to some extent, and the best silicon crystals are grown by the so-called "floating zone" method, the molten silicon being supported by means of its own surface tension.(8) To obtain intrinsic silicon the concentration of carrier-producing impurities, sometimes called "active" impurities, would have to be reduced to less th 10^{10} cm^{-3}. We should then have a room temperat resistivity of about 250000 Ω cm. It is now possible to gr single crystals of silicon by the floating zone method havi a resistivity of the order of 10^4 Ω cm, corresponding to active impurity concentration of about $2 \cdot 5 \times 10^{11}$ cm Unfortunately only fairly small crystals may be grown this method and, for larger crystals grown in a crucib resistivities of the order of 100 Ω cm are more commo corresponding to active impurity concentrations of order of $2 \cdot 5 \times 10^{13}$ cm^{-3}. It has long been suspected th crystals which have concentrations of active impurities the order of 10^{13} cm^{-3} may still have other impurities much higher concentrations. Recent work at the Bell Te phone Laboratories and in our laboratory has shown this be the case. Concentrations of 10^4 to 10^5 times greater oxygen and hydrogen have been found.(9, 10) It has genera been thought that such impurities would be harmless as th do not appear to affect the equilibrium carrier concentrat to any great extent. Experiments by Hogarth and Johnson in our laboratory have shown that high quality silic crystals generally contain considerable quantities of oxyg This is not surprising as molten silicon reacts with silic oxide forming the crucible in which it is usually me What is surprising at first sight is that the inclusion of oxyg in the grown silicon crystal has a marked beneficial e on the minority carrier lifetime. When silicon crystals grown in a good vacuum a certain amount of oxygen app to evaporate from the outer parts of the crystal, and may have their lifetime reduced from about 100 μs to ab 1 μs. Clearly we should not expect such an effect in absolu perfect crystals, and the oxygen appears to render innocu certain types of defect which exist in the crystals. Some these are almost certainly mechanical defects known dislocations, which are known to have an adverse effect the lifetime.

MECHANICAL IMPERFECTIONS

The study of dislocations in germanium and silicon advanced greatly in the last few years, mainly due to development of etching techniques for showing them The simplest form of dislocation may be envisaged as edge of an extra plane of atoms inserted in the crystal (Fig. 1). The dislocation then forms a line running throu the crystal. The position of the dislocation is marked w a cross in Fig. 1. When a dislocation meets the surfac state of strain exists around it and an etching solution atta the surface preferentially at such points. In metals wh have been studied by this means, dislocation densities, wh give a measure of the departure of the crystal from perfecti are generally of the order of 10^6 or more per square ce metre. With silicon and germanium, crystals may now

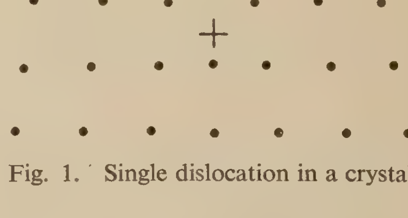
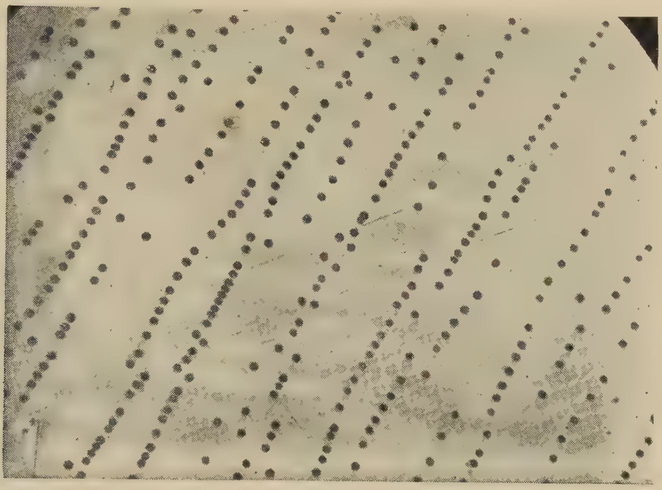


Fig. 1. Single dislocation in a crystal

vn which are so perfect that dislocation densities of cm^{-2} or less are common. Techniques have been loped by Dr. R. L. Bell in our laboratory whereby these ocations may be inserted at will and in controlled direc- s during crystal growth and their study is opening up e very interesting new fields of research. This is one of fruits of the efforts that have gone into the production of tals of high purity and perfection.

Fig. 2 is shown a series of etch pits obtained by Bardsley Bell(11) marking the intersection of dislocations with the ace of the crystal. It will be noticed that they have been d up along certain preferred directions in the crystal to n "walls" of dislocations.



[Reproduced from *Journal of Electronics*]

Fig. 2. Etch pits showing dislocations in an InSb crystal

IMPACT ON THE PHYSICS OF SOLIDS

he high perfection and purity of crystals now available made possible a number of fundamental experiments ch could not have been carried out with less good erials. The most striking of these is the cyclotron nance experiment in which the electrons in the solid, aving virtually as if they were free, are made to move in ular orbits in a magnetic field.(12) The relationship veen the frequency with which the orbit is described and magnetic field depends on the "effective" mass of the tron. It is found that the electron does not have its "free" s and that in silicon and germanium the "effective" mass ends on the crystal orientation. By this means a fairly plete picture of the electronic band structure of silicon germanium has been built up.(12) This has turned out e far more complex than was originally envisaged. Many r interesting phenomena associated with the interaction lectrons and the vibrations of the atoms of the crystal come to light. In a nearly perfect crystal these are not ked by interaction with impurities and lattice imper- ons. New light has been shed on conduction phenomena in particular on Ohm's law. Let us digress for a moment onsider this very fundamental law.

OHM'S LAW

hen current electricity is taught to students, it is generally d that Ohm's law holds in conducting solids except in intense electric fields. It is well known that it breaks down at quite low applied voltages at rectifying contacts and the like, but one gets the impression that for all practical purposes Ohm's law always holds for conduction through the solid. While it is true that departures from Ohm's law in metallic conduction are difficult to observe, this is by no means true for semiconductors, and departures from Ohm's law at quite low fields have recently been observed in germanium in our laboratory by Arthur, Gibson and Granville(13) and by Gunn.(14)

It is interesting to consider how such departures come about. Ohm's law is a consequence of the fact that an electron, drifting in a crystal in an electric field, comes rapidly into thermal equilibrium with the atoms of the crystal. The energy it receives from the field is rapidly given up to excite lattice vibrations, and is dissipated as Joule heat. In a metal, the mean square velocity $\overline{v^2}$ of the electrons taking part in conduction is high, being given by

$$\tfrac{1}{2}m\overline{v^2} \simeq E_F$$

where E_F is the Fermi energy, and may have a value of several electron volts. Any small increase in the mean square velocity of the electron would hardly be noticed. In a reasonably pure semiconductor, however, the mean square velocity of an electron, like that of a molecule in a gas, is given by

$$\tfrac{1}{2}m\overline{v^2} = \tfrac{3}{2}kT$$

where k is Boltzmann's constant and T the absolute temperature. At room temperature kT has a value of about 1/40eV and so $\overline{v^2}$ is very much smaller than in a metal. Thus an appreciable increase in $\overline{v^2}$ might be produced by an electric field, provided the interaction of the electron with the crystal is sufficiently weak.

In an imperfect crystal, exchange of energy between the electron and the crystal is greatly facilitated by impurities, dislocations, etc. In a very pure crystal the exchange is much less efficient and the electron's mean-square velocity may increase appreciably; we may say, in fact, that the electrons become "hot" as their effective temperature increases. They will not become infinitely "hot" as the coupling with the lattice is known to increase with their effective temperature

They will therefore finally reach a saturation drift velocity beyond which further application of field will make them go no faster. We therefore might expect to get a current voltage curve like that shown in Fig. 3 in which drift velocity, which is proportional to the current, is plotted against the applied field. Such a characteristic was predicted theoretically some time ago by Shockley(15) and found experimentally by Ryder.(16) More recent measurements in our laboratory already referred to(13, 14) have given the form of the curve in much greater detail. Perhaps the most surprising new result is the observation that, for good specimens of germanium, departure from Ohm's law starts at as low a field strength as 10 V/cm.

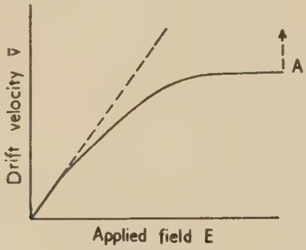


Fig. 3. Current voltage curve showing large departure from Ohm's law at high fields

For sufficiently low frequencies, absorption of energy in a conductor is proportional to the resistance, when Ohm's law holds. When it does not the absorption is proportional to the differential slope resistance (i.e. to the rate of change of average drift velocity with field). It follows that, in the saturation range in Fig. 3, the absorption due to the superposition of a small alternating field on a steady field will be very small, as compared with its value in the absence of a steady field. Gibson(17) has shown that this effect may be observed at microwave frequencies and provides the basis of an elegant microwave switch.(13) A small wafer of germanium is inserted in a wave-guide. With no steady electric field its absorption may be greater than 20 dB. On switching on the field it may be reduced to the order of 2 dB, largely due to reflexion loss alone, and this may be removed by suitable matching.

AVALANCHE INJECTION

As the voltage applied to the crystal is increased still further, a point is reached at which a sudden increase in current takes place. Here we have the phenomenon of the current avalanche, in which secondary current carriers are produced by ionization of the atoms of the crystal. Suppose we have a small area contact which does not normally inject minority carriers (say holes in *n*-type material). The field near such a contact may be shown to exceed the critical field for avalanche formation for a quite low applied voltage. As soon as an avalanche is created, electron-hole pairs are formed, the holes being swept into the body of the crystal—thus we have avalanche injection. This phenomenon has been studied by Gunn(18) and some interesting devices including a very high-speed switching diode have been developed as a result.

Another phenomenon which appears to cause a departure from Ohm's law is that of carrier exclusion. If we have a contact which does not inject minority carriers, a considerable proportion of the carriers may be swept by a fairly small field (in pairs of electrons and positive holes to preserve electrical neutrality) from a pure sample, with consequent increase in resistance. This gives rise to a non-linear variation of current with voltage of the form shown in Fig. 4, the initial slope corresponding to the resistivity before an app ciable number of carriers is swept out, and the final slope the limiting value of resistivity when all the carriers that c be have been removed. This is determined by the number

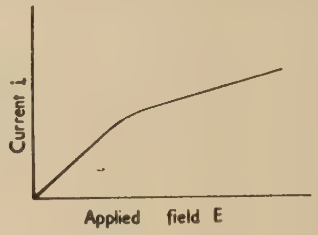


Fig. 4. Current-voltage curve due to carrier exclusion

carriers arising from impurities. As these are mainly of c sign they cannot be removed in pairs. This effect might regarded as a contact effect and not as a fundamen departure from Ohm's law, although the increase of resista occurs throughout the specimen, so long as its dimensio are not too large.

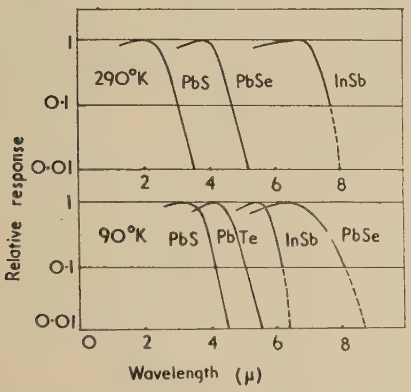
COMPOUND SEMICONDUCTORS

In the past few years a number of semiconductors ot than germanium and silicon have been extensively stud with a view to using them as the basis of various electro devices. These have been largely compound semiconduc of two distinct classes, (i) polar compounds such as P PbSe, PbTe, and (ii) intermetallic compounds such as I GaAs, etc. The main interest in the former group and a in InSb has been through their use as detectors of infra radiation. In spite of a great deal of effort it must be adm that crystal perfection and purity, comparable with what been obtained in germanium and silicon, have not yet h achieved. Apparent impurity concentrations less than ab 10^{14} cm^{-3} are rare, and in any case are almost certainly to partial compensation. In spite of this, material which intrinsic at room temperature has been prepared. The c difficulty with these compound semiconductors is that addition to the removal of foreign impurity atoms from crystal one must remove excess of one or other of the co stituents and the resulting vacant lattice sites. This invol a very exact stoichiometric balance of the constituen Various ways of controlling this balance have been suggest such as growing single crystals in a controlled atmosphere one of the constituents, and this has been used with so success for InSb. Recently A. C. Prior working in laboratory has succeeded in growing single crystals of Pb from the vapour of PbSe, with the admixture of a control amount of selenium vapour. It must, however, be admit that much work still remains to be done before the sa perfection and purity as for the simple element se conductors can be achieved.

Compound semiconductors such as PbS and InSb much more difficult to study in detail than germanium a silicon. There are two main reasons for this. Firstly, th have small forbidden energy gaps, and so one is nearly alw dealing with mixed conduction (both electrons and posit holes). Also, the small effective electron mass, particula in InSb, leads to a marked dependence of Hall effect, etc., the magnetic field used for its measurement. Secondly, minority carrier lifetime is less by a factor of at least 10^3 compared with high quality silicon and germanium. T implies that the diffusion length is also much smaller so th

mobility is difficult to measure directly. Various methods
ɔvercoming these difficulties have been proposed. In
cular, a method has been developed in our laboratory
; the spectral variation of photoconductivity and photo-
romagnetic effect. Unfortunately it is rather complex
depends on fairly advanced theoretical considerations.
theory of the method has been given by G. G. Mac-
ne(19) and it has been applied with success to InSb by
V. Goodwin.(20) Although, as stated, the method is
ewhat complex, it gives very full data on the semi-
uctor under observation, including mobility of both
rons and positive holes and intrinsic carrier density,
ell as bulk and surface recombination rates.

ere is, at the moment, no evidence that any of these com-
d semiconductors are likely in the near future to super-
silicon and germanium as the basis for transistors and
ar devices. The lead salts in the form of evaporated
s have long been used successfully for infra-red
ctors.(21) Single crystal InSb has recently also been used
essfully for the same purpose by Hilsum and Ross(22)
make use of the photo-electromagnetic effect and also
Avery, Goodwin and Rennie(23) employing the more
l photo-conductivity. Detectors made from single-
al material have obvious advantages over the evaporated-
types which involve complex sensitization processes. A
h greater spectral range is also covered by InSb at room



g. 5. Spectral response of infra-red detectors using PbS, PbTe, PbSe and InSb

erature. The spectral response of a single-crystal InSb
ctor is compared in Fig. 5 with that of detectors using
orated layers of PbS, PbTe and PbSe.

OTHER MATERIALS

though semiconductors have undoubtedly played the
inant role in the development of "solid-state" electronics,
are by no means the only types of substance involved.
uch modern electronic circuitry,(24) such as that used in
matic control systems and electronic digital computers,
ell as in microwave techniques, certain ferrites are being
a great deal. As an example we may consider the use
ferrite ring as a two-state store. Such stores are used for
ry digits in a computer. A ferrite with a very "square"
eresis loop is needed, such as shown in Fig. 6. The
s marked A and B corresponding to magnetic saturation
vo directions are used to represent the digits 0 and 1.
ching from B to A is accomplished by supplying a magnetic
by means of a current through the ring sufficient to carry
ate of magnetization to the point C and then reducing it to zero. Similarly switching from A to B is accomplished by a current of reversed polarity. The change in flux through another circuit threading the ring can give information that the change in state has taken place and so supply the "read" function as well as the "write" function for use in a computer.

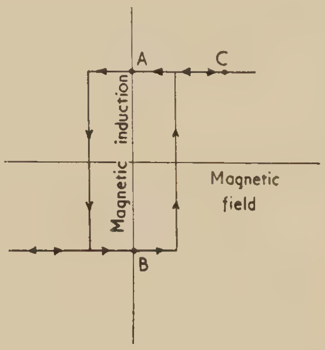


Fig. 6. Hysteresis loop for a ferrite

Ferrite rings of this kind are switched very conveniently by means of junction transistors and it is possible to plan a computer using these circuit elements with no thermionic valves. A new computer, at present under construction in our laboratory, is being designed in this way.

One of the outstanding features about this type of electronic circuitry is its extreme reliability as compared with conventional circuitry using thermionic valves. In complex electronic equipment using thousands of valves the latter set the main limit to reliability. This is borne out by our own experience with our present digital computer. It is too early to give exact figures for reliability of junction transistors but mean lives of the order of a million hours are indicated for the most modern types. With such a mean life, equipment with ten thousand transistors can be contemplated. This means that many operations now carried out by analogue methods may be done digitally with greater accuracy. There are other great advantages in using transistors, such as low power consumption, small operating voltages, etc., but in the end it seems likely that their main advantage will lie in their long effective lifetime.

There are a number of other types of crystalline solid which are likely to contribute to the new electronics. As a final example we may consider the paramagnetic salts. It has been shown by Gordon, Zeiger and Townes(25) that a microwave oscillator may be made by using stimulated emission from ammonia molecules. It has also been proposed that this effect could be used to provide a low-noise amplifier. Such a device has been termed a "maser." It has also been suggested(26) that single electron spin levels in a magnetic field might be used in the same way leading to a "solid-state maser," and preliminary experiments using doped silicon have shown promise. In the simplest case we consider two levels A and B as shown in Fig. 7(*a*). For an electron with spin $\frac{1}{2}$, in the usual notation, the separation ΔE of the levels in a magnetic field H will be given by $\Delta E = 2\mu_B H$, where μ_B is the Bohr magneton. If we apply a radiofrequency field of frequency ν given by $h\nu = \Delta E$, excitation will take place from the lower to the upper level with consequent absorption, so long as the population of the lower level is significantly greater than that of the upper.

If the magnetic field is swept quickly through the value for resonance, the upper level will be found to be more highly populated, and this condition would last for a significant time if the relaxation time were long enough. The spin system would then be encouraged to emit radiation by the process of stimulated emission. If the sample were placed in a resonant cavity, and the emission rate were sufficient to overcome the losses in the cavity, the system would oscillate.

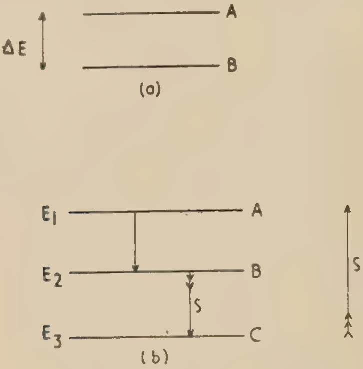


Fig. 7. Energy levels for "maser"

A method of achieving the same result without switching a magnetic field has recently been proposed by Bloembergen.$^{(27)}$ Three energy levels E_1, E_2, E_3 are used such that $E_1 > E_2 > E_3$ and $E_1 - E_2 \neq E_2 - E_3$ [Fig. 7(*b*)]. These conditions are provided by the electron spin levels in certain salts whose paramagnetic ions have total spins of 3/2 or more. A fairly strong microwave field of frequency $\nu_{13} = (E_3 - E_1)/h$ is applied to a resonant cavity and this tends to "over-populate" the upper level of energy E_1. Transitions from this level induced by spin-lattice interaction take place to the level of energy E_2 and if the conditions are right, this level becomes "over-populated" as compared with the level of energy E_3. If the emission at frequency $\nu_{23} = (E_2 - E_3)/h$ is sufficient to overcome the cavity losses at this frequency (to which the cavity is also tuned) oscillations will take place, and the system works as a frequency changer. This effect has recently been observed by Scovil, Feher and Seidel in the Bell Telephone Laboratories.$^{(28)}$

If the emission is not quite large enough to produce oscillations, a small external radiofrequency field of frequency ν_{23} will cause stimulated emission from the "over-populated" middle energy level and so will be amplified. For a variety of reasons it is desirable that such a device be operated at very low temperatures, preferably in the liquid helium range, and there is the attractive possibility of making a very low-noise amplifier. This will serve to indicate some of the extremely interesting new developments which may be expected from the use of crystalline solids in electronics.

There was a time, not too long ago, when some physicists tended to look down on electronics as "fiddling with wires and valves." This can hardly be said of the new electronics which involves a vast amount of quite fundamental physics.

PHYSICS AND THE ELECTRONICS ENGINEER

This leads us to consider the position of the future electronics engineer. It is quite clear that he will have to know a great deal more modern physics than his predecessor who had to deal mainly with vacuum tubes. The subtle effects which are being used arise very largely from the quantum theory of electrons and cannot readily be expressed in terms of classical electromagnetic theory. Undoubtedly as time passes many of the devices which at the moment are new and physically interesting will to the electronics engineer become "components." There will still undoubtedly be a great deal of physics involved in their manufacture. Thus it see quite clear that a great many staff of all grades with a traini in modern physics will be required for the great expansi of the new electronics which will undoubtedly take pla The vast amount of research effort in many countries whi is now being concentrated in this field of physics, not only university and government-sponsored laboratories, but al in industrial research laboratories is a clear indication of importance in the technological developments of the futu Much of this research is aimed at development of "devices but its important reaction on the advance of our basic kno ledge of the properties of solids should not be underestimat Many of the most important advances in the past few yea have been due to technological developments pursued p marily for industrial ends. It is up to the research physic to stimulate such developments and to use them at once wh they help to advance his research. Only in this way is t rapid rate of progress of the past few years likely to maintained. That there is a vast amount still to be achie in this field, I hope I have made clear in this article.

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Energy stabilization of an electrostatic accelerator

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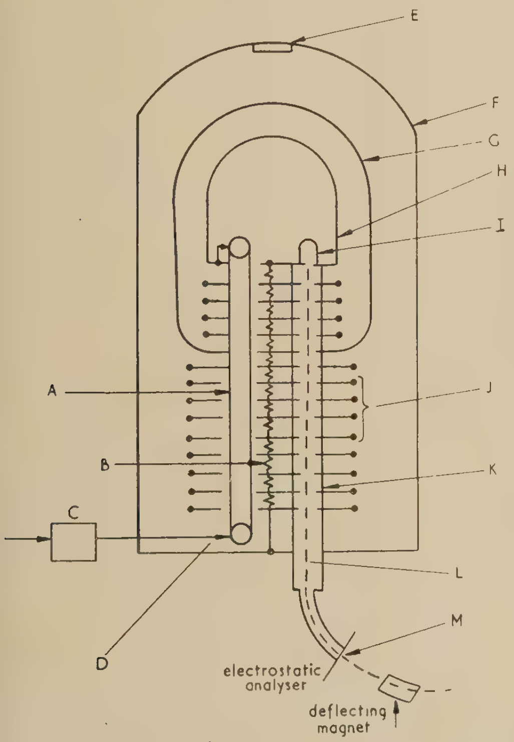
The energy of the ion beam from the accelerator is measured and stabilized with an accuracy of better than 0·1%. The main energy measuring device is an electrostatic analyser which is energized from a stabilized power supply whose voltage is referred to standard cells. A generating voltmeter is used as an auxiliary measuring device, and a method is described by which a very fast response may be obtained from this instrument. An electron beam loading the generator is used as a fast acting control device, while long term variations are taken up by automatic control of the spray current.

1. INTRODUCTION

some of the work being done with the Aldermaston trostatic generator[1] developed by Associated Electrical ustries Ltd. it is desirable that the energy of the ion beam uld be stabilized and measured with an accuracy of better n 0·1%. This paper describes the equipment which bles this accuracy to be obtained.

he main parts of the accelerator are indicated in Fig. 1. -50 kV d.c. supply energizes corona needles which "spray" rge on to an endless rubber belt, which carries the charge he high voltage terminal where the charge is removed by her corona needles. To make the vertical voltage gradient uniform the generator stack plates and ion accelerator tube plates are connected to tappings on the stack resistor chain. The generator is pressurized, and the radial high voltage gap is divided into two by an intershield which is supported by one of the stack plates.



ig. 1. Diagram defining parts of the electrostatic accelerator

, belt; *B*, stack resistors; *C*, spray power pack; *D*, corona eedles; *E*, generating voltmeter; *F*, pressure tank; *G*, interield; *H*, high voltage terminal; *I*, ion source; *J*, stack plates; , accelerator tube; *L*, ion beam; *M*, exit slit.

Estimating the generator voltage by measuring the current in the stack resistors is inaccurate due to the effects of ionization currents in the insulating gas, and of currents to intermediate accelerator tube electrodes. A generating voltmeter, placed as shown in Fig. 1, is better, but can only measure the intershield potential directly. A precise measure of the ion beam energy is obtained by using a 63·2° electrostatic analyser.[2] If the ion beam passes between the molybdenum jaws forming the analyser exit slit, the particle energy is given by $eV = Xe\,a_0/2d$, where X is the potential applied between the analyser deflector electrodes, a_0 is the mean radius of these electrodes and d is their spacing. If the beam energy differs slightly from this value the beam will hit one or other of the analyser jaws, and so a control signal to correct the generator voltage can be obtained. Thus, the equipment to be described falls into two parts, firstly, a very stable high voltage supply of accurately known value for the analyser, and secondly a feedback control system to keep the ion beam passing through the centre of the analyser.

2. MEASUREMENT AND STABILIZATION OF THE ANALYSER VOLTAGE

The design of the analyser called for a deflector voltage balanced with respect to earth, variable between + and −5 kV and + and −50 kV and known to better than 0·05%. This range of adjustment would correspond to a generator voltage range of 0·5 MV to 5 MV, but the upper limit is greater than the design value for the generator. In practice this upper working limit is set at about 3·2 MV by the accelerator tube. The equipment had to be convenient for remote control from either of two positions. Currents flowing to the deflector bars were expected to be small, but in fact were found to reach 0·5 mA or more in the presence of a large ion beam. Under normal working conditions the beam passing through the exit slits of the analyser and reaching the target is about 15 μA but values as high as 50 μA have been used.

2.1 *Analyser voltage measurement*

The method of measurement chosen was to use a fixed resistance potential divider (R_1–R_4) and to measure the voltage appearing across it with a precision potentiometer, the voltage across which was standardized automatically by comparison with eight Weston Standard Cells in series. The balance condition in both cases was detected by galvanometer amplifiers. The basic circuit is shown in Fig. 2 from which

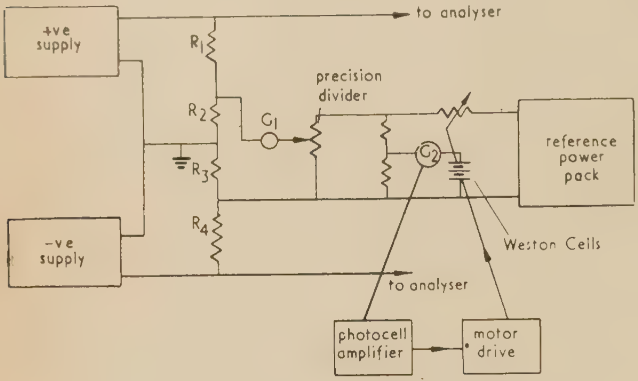


Fig. 2. Analyser voltage measuring circuit

it will be seen that it is essential for the leakage to earth from the reference power supply to be kept to a minimum and great care is needed here. Galvanometers G_1 and G_2 are convenient balance detectors in this respect as the associated photocell amplifiers can be at earth potential.

2.2 *Analyser voltage stabilization*

The deflexion of the measuring galvanometer provides a signal E_g for feedback purposes. Unfortunately its frequency response is limited and it is unable to respond to ripple frequencies from the power supply. It is therefore necessary to take fast signals E_+ and E_- from capacitive dividers across the h.t. lines. In addition, unbalanced load currents upset the balance with respect to earth and an error signal E_b to correct this is obtained from a resistor R_5 connecting the midpoint of the potential dividers (R_1–R_4) to earth. The various error signals are shown diagrammatically in Fig. 3.

The problem is now to combine these signals into a fast acting stable feedback loop. The first essential is a fast acting control device. Conventional series valves in both the positive and negative lines are used and the varying bias that they require is transmitted to them by means of r.f. links. This technique enables most of the error amplifier to remain at earth potential. The series valves available are limited to 10 kV between anode and cathode and so the range of d. control is quite restricted. This is overcome by feeding th main high voltage power pack from a motor-driven Vari transformer which is controlled by the mean bias on th series valves. If this is excessive the voltage input to the e.h transformer is automatically reduced until the anode voltag of the series valves are at the midpoint of their operati range.

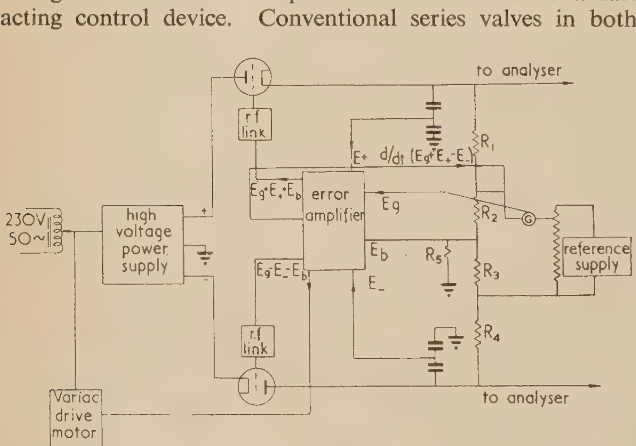


Fig. 3. Block diagram of analyser supply showing error signals

In addition to the usual stability requirements, caref consideration has to be given to stability of the feedba loop under conditions of gross overload. If the analys sparks over due to poor vacuum conditions a large volta is applied to the error amplifier from the capacitive potenti divider. If this is allowed to block the fast feedback chann while leaving the galvanometer channel connected t stabilizer will oscillate keeping the fast channel in a block condition. Protective neons on the capacitive dividers, ca with coupling time constants and local feedback to t galvanometer within the loop enables the recovery from flashover to be almost critically damped and complete with about 2 s.

2.3 *Circuit details*

A simplified circuit diagram is shown in Fig. 4.

2.3.1 *Analyser high voltage tank.* In the interests of s plicity and reliability, a 50 c/s oil immersed power sup was chosen. The oil tank also contains the series con valves and the capacitors forming the high voltage side the capacitance dividers. The output leads plug i porcelain lead through insulators which also form the suppo for the transformers in the r.f. links.

2.3.2 *Potential dividers.* The high voltage dividers de mine the ratio of the analyser voltage to the reference volt and thus their stability is of utmost importance. They ea have a ratio of about 2000 : 1 and are built of commerci 100 kΩ wire-wound resistors arranged in Perspex frames a surrounded by anti-corona spinnings, the potentials of whi are determined by an auxiliary divider chain. The lo arms of the main dividers each consist of a 22 kΩ resist wound with wire similar to that used for the 100 kΩ unit The ratios were measured at the working voltage using t method due to Rymer(3) and were found to be consta within the limits of measurement which was 0·02%.

2.3.3 *Galvanometer amplifiers.* The two galvanomete photocell amplifiers are mounted side by side in a light-tig box fastened to a wall to reduce vibration to a minimu The light beam from each galvanometer falls on a tw vacuum photocell with the two halves connected in serie This arrangement produces a very large change of volta for a small movement of the light spot but due to the sma photocurrents the output impedance is very high. The ou put signals are fed to ME1400 electrometer valves used cathode followers so that the grid impedance does not redu the sensitivity appreciably. When the setting of the potenti meter is changed large currents flow through the galvan meter, but it is essential that the light spot does not leave t photocell and so each galvanometer is fitted with adjusta coil stops. If the voltage setting potentiometer is set to f output with the power pack variac at minimum this curre reaches a value of 1 mA, and even with the coil stops careful adjusted it is impossible to prevent this overload fro swinging the light beam off the photocell so that furth protection is needed. A resistor of 33 kΩ is connected series with the galvanometer, and a pair of rectifiers parallel opposition across the galvanometer and resistor gi sufficient protection without much loss of sensitivity.

uring the initial setting up the galvanometers are adjusted hanically so that the light falls centrally on the photocell, subsequent drifts due to temperature changes, etc., essitate small adjustments from the remote position. se are most conveniently made electrically by injecting a ll current from a high impedance circuit into the galvano- er. The current is controlled by a small motor-driven entiometer operated by a key switch on either control el.

the output from either galvanometer amplifier falls out- a certain range, relays energize motors which drive er the "variac" feeding the e.h.t. transformer or the of the standardizing resistor to bring the amplifier back he middle of its range. The outputs of these amplifiers also displayed at the remote control points and are used et the zero position of the galvanometer.

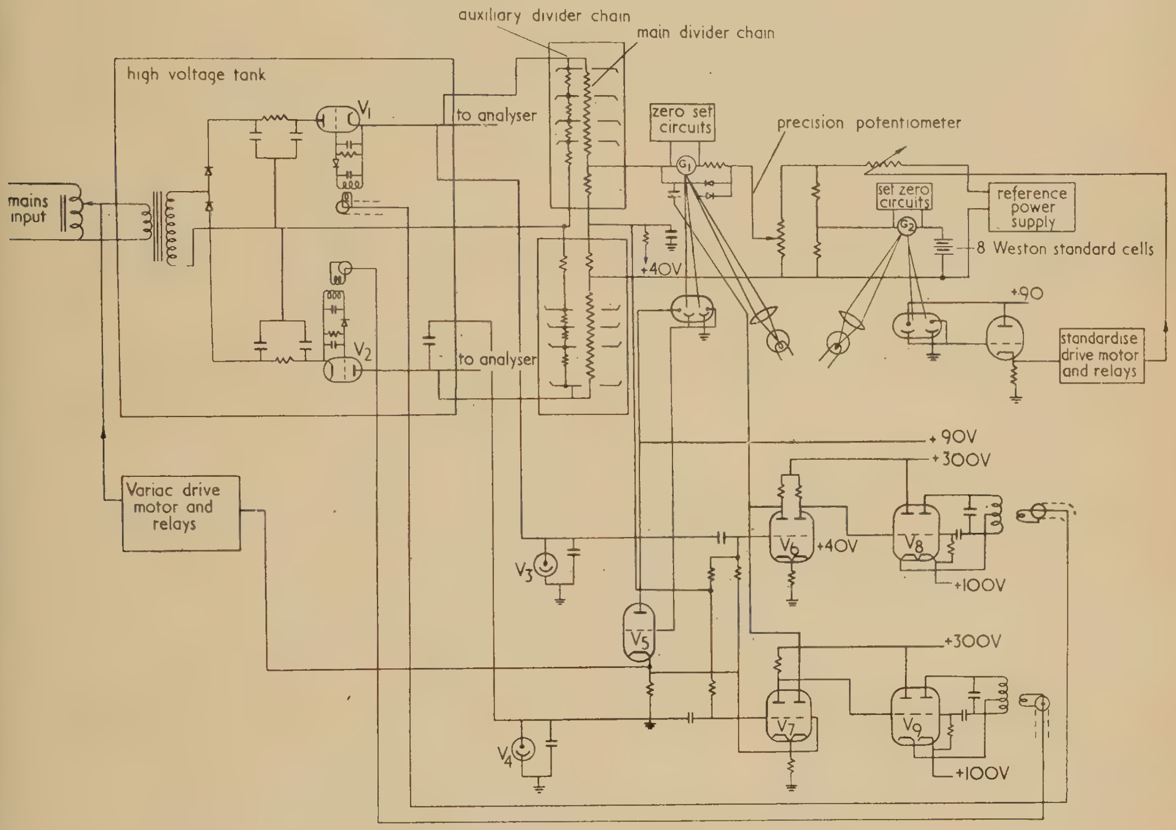


Fig. 4. Simplified diagram of analyser power supply

3.4 *Error amplifier*. The essential parts of the error lifier are shown in Fig. 4. There are two channels esponding to the series valves V_1 and V_2. Each channel ists of a cathode coupled d.c. amplifier V_6 and V_7 driving node modulated r.f. oscillator V_8 and V_9 which is link pled to the r.f. transformer in the oil tank. The cathode pled pairs each receive three error signals and the combined r signals appear in their anode circuits. One anode of pair feeds the modulator for the appropriate r.f. link st the "spare" anodes are connected together and provide ltage for damping the galvanometer. It will be seen that protective neons V_3 and V_4 limit the amount of blocking can take place and that while the fast loop is broken to overload the slow galvanometer loop is also put out ction. The centre point of the dividers is taken to a potential of +40 V rather than to earth. This is because the balancing circuit was a late addition and it was simpler to do this than to provide a negative line and make extensive alterations to the d.c. operating conditions of the valves. The result is a permanent unbalance in the e.h.t. supply of about 40 V which can be tolerated. The gain of the galvanometer loop is greater than 1 000 and is adequate for any reasonable change of load. That of the balancing loop is between 50 and 100 and is sufficient to ensure that the balance is maintained within 1%.

2.3.5 *Reference voltage supply*. The voltage supply is essentially in two parts. The first consists of a very stable d.c. power pack using a battery reference. The design is fairly conventional. There is a two stage d.c. amplifier the valves of which have stabilized heater currents and there is compensation for mains voltage fluctuations. The only special feature of the circuit is that great care is taken to keep the insulation resistance to earth as high as possible. To this end the amplifier is mounted on an insulating sub-chassis and the transformer has extra insulation between primary and secondary.

The standardizing circuit consists of the standard potential divider, the galvanometer amplifier G_2, eight standard cells in a thermostat and a motor-driven variable resistance controlled by the galvanometer amplifier. The variable resistance enables the reference voltage to be adjusted over a range of 4 parts in 1 000.

Under normal operating conditions the standardizing circuit only sets infrequently, but it has the valuable property of compensating for the warming up drift of the reference power supply so that it is unnecessary to leave this running continuously and the equipment can be operating with full accuracy within a few minutes of switching on.

The reference potentiometer setting is controlled by banks of push buttons and the shafts which operate the potentiometer switches also set the reference voltage and gain of the generating voltmeter amplifier in the main machine stabilizing system.

3. STABILIZATION OF THE MAIN MACHINE

An error signal for controlling the generator voltage is derived from the currents to the exit jaws of the electrostatic analyser, but this by itself is not sufficient. If the generator voltage differs from the desired value by more than ±1% the ion beam will strike the analyser bars, and the jaw current will be zero. A generating voltmeter is therefore used to provide an error signal for correcting gross errors in the generator voltage. A circuit is introduced in the generating voltmeter error amplifier such that if the error in generator voltage is less than $\pm\frac{1}{2}\%$, the generating voltmeter does not provide any correcting signal, and the analyser has full control. This will be referred to as the backlash circuit, although it is not a true analogue of mechanical backlash.

The simplest method of controlling the voltage of a Van de Graaff generator is by varying the spray current, but if this method is applied by itself in an automatic control system the feedback loop then contains the high voltage electrode time constant of about 3 s, and also a time delay equal to the belt transit time (about 0·15 s) so the maximum loop gain which can be used is quite low.(4)

A fast control can be obtained by varying the load on the generator. Various methods are possible(5–9) and the one chosen is to fire a variable beam of electrons up the main accelerator tube. The transit time is negligible and the limitation on loop gain is largely removed. It is desirable to keep the mean current from the electron gun less than about 25 μA to minimize X-ray production at the top of the accelerator tube. A spray current controller is incorporated which can either maintain the electron gun current at the desired value or stabilize the spray current.

3.1 *Main stabilizing loop*

The stabilizing circuits are shown in block form in Fig. 5. Signals from the two jaws are amplified, subtracted, combined with a signal from the generating voltmeter and then fed *via* an r.f. link to the grid of the electron gun, which is at a potential of about −7 kV. The electron gun current is measured at the earth return of its power supply, and a signal is fed from this point to the spray current controller.

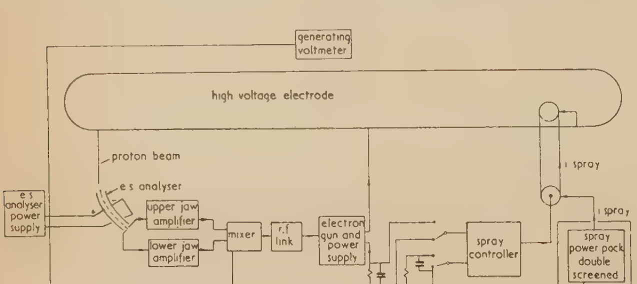

generating voltmeter
high voltage electrode
proton beam
e s analyser
e s analyser power supply
upper jaw amplifier
lower jaw amplifier
mixer
r.f link
electron gun and power supply
spray controller
i spray
i spray
spray power pack double screened
i spray
amplifier
backlash circuit
reference voltage for generating voltmeter
reference voltage for spray current stabilization
reference voltage for electron gun current stabilization

Fig. 5. Block diagram of machine stabilizer

The loop gain of the system depends on the ion bea current and other factors not strictly controlled. A typic value is probably 10^4, which is well above the value of 5 required for satisfactory operation, and below that of 5.1 at which it is estimated that oscillation will occur.

3.2 *Generating voltmeter*

The stator of the generating voltmeter has 16 sectors co nected alternately in two sets of 8, while the earthed rot has eight metal sectors with eight equal gaps between ther so that each set of stator plates is alternately exposed to ar shielded from the electric field due to the high voltage te minal or intershield and so produces an alternating outp potential of amplitude proportional to the generator voltag The generating voltmeter rotor is driven at approximate 3 000 rev/min, and so the carrier frequency of the generati voltmeter output is approximately 400 c/s. To make t calibration of the instrument as far as possible independ of rotor speed and amplifier gain, a capacity feedback circ similar to that described by Fortescue and Hall(4) has be used.

A method of using the generating voltmeter has be devised in which the speed of the response of the instrum is not limited by its carrier frequency, but only by the hi frequency response of electronic amplifiers. This considera eases the problem of designing a feedback system of wh the generating voltmeter is a part. The method is a for of the general one of obtaining a wide bandwidth by paral connexion of circuits whose pass bands are comp mentary,(10, 11) but the way in which the signals are deri is unusual. The response of a push-pull generating voltm circuit to a step function change in the potential to measured was analysed and it was found that the differe of potential between the two output points of the ampli (the antiphase output) consists of an alternating signal who amplitude follows the input correctly and with only sm transient terms, while the mean potential of the output poi (the inphase output) changes suddenly and returns expon tially to its normal value. If the antiphase output is rectif and filtered with a single *R-C* filter its output rises expone tially from zero to its final value. If the filter time consta of the antiphase signal is made equal to the decay ti constant of the inphase signal and the two signals are adde the gains being suitably adjusted, the total response is a sha rise followed by a level top, i.e. it is perfect. An analysis the circuit for an ideal case and a discussion of the resid imperfections are given in the Appendix.

The circuits are outlined in Fig. 6, where V_1 to V_4 form t generating voltmeter amplifier. Its two outputs are coupl through V_5 and a transformer to the detector V_6. T detector is compensated for heater voltage variations by and is also arranged so that the charging and discharg time constants of its filter are equal. The inphase signal taken from a potentiometer which is adjusted to balance the carrier frequency signals. The detector output, the phase signal, and a reference voltage are mixed by V_8 and The circuits are designed so that none of the valves preced V_8 and V_9 limits under any conditions, and while V_8 and can limit, they never take grid current. The later stages all direct coupled. Thus false output signals due to recovery periods of blocked amplifiers never occur. T reference voltage supply potentiometer is ganged with reference potentiometer in the analyser supply stabilizer, that only one manual adjustment has to be made when it desired to change the generator voltage. The supply volta to the generating voltmeter reference potentiometer may sted by the tracking control to take up any drifts in the rating voltmeter calibration due, for example, to changes e current distribution in the generator if the intershield use. The error signal appearing at the anode of V_8 is er amplified and then fed to the backlash circuits, V_{10}– whose output as a function of input is shown in Fig. 7.

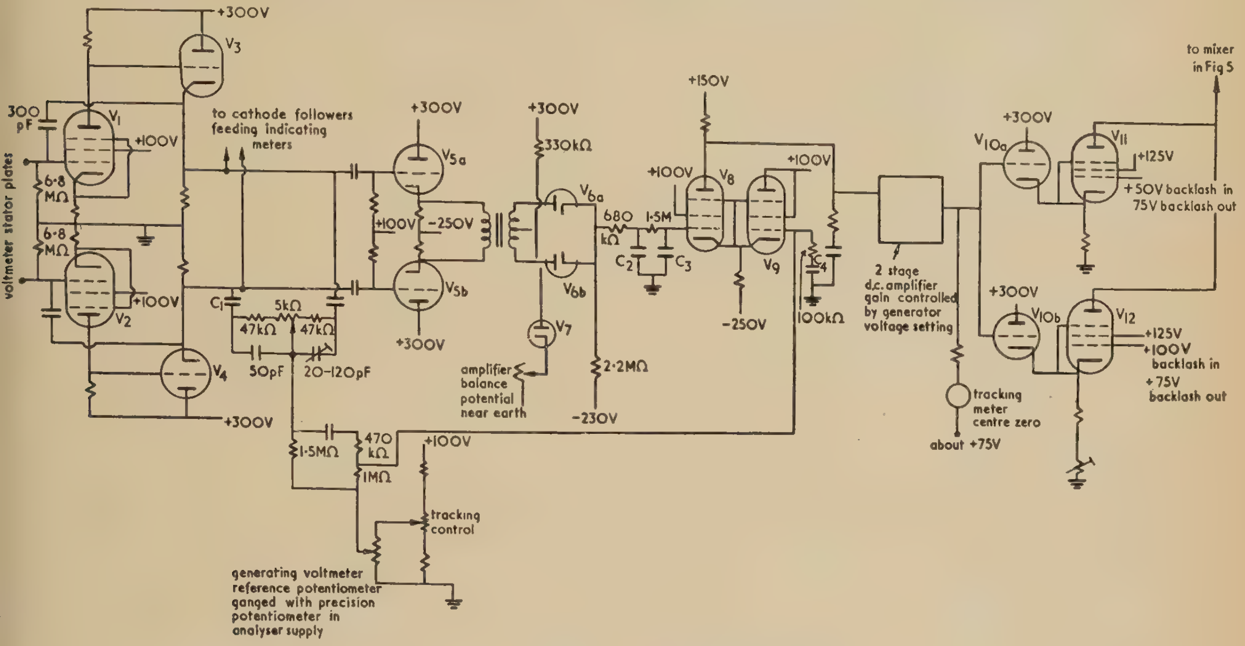
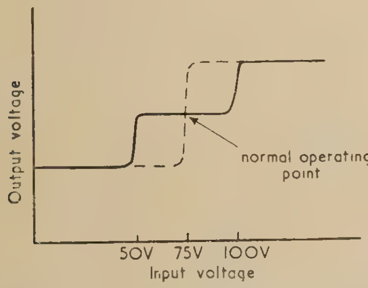


Fig. 6. Generating voltmeter circuits

C_1, 1μF; C_2, 0·25 μF; C_3, 0·01μF; C_4, 0·002 μF.

e generator is operating at its correct voltage and the its are accurately alined the operating conditions will s shown, and the circuit will have zero gain for small ges of input potential, but large input signals produce an ut which gives full control of the electron gun. The l from the analyser jaws fails if the generator voltage is ror by more than 1%. A gain control in the generating neter error amplifier is ganged with the generator voltage g potentiometers and ensures that the backlash width esponds to a generator voltage error of $\pm\frac{1}{2}$% whatever perating voltage. The output of the backlash circuit is o the mixer of Fig. 5, so combining the control signals



g. 7. Input/output characteristics of backlash circuit

the analyser and the generating voltmeter. For opera- without the analyser the backlash may be cut out as n by the dotted curve in Fig. 7. The loop gain then s between 10^3 and 10^4, according to the generator ating voltage, while the gain at which oscillation would occur is about 3×10^6.

3.3 *Spray current controller*

The spray needles are placed close to the belt, opposite the bottom pulley, as shown in Fig. 5. A control amplifier can vary the pulley potential over a 12 kV range, so controlling the effective spray voltage and thus the current. A spray current feedback signal is obtained across a resistor in the earth return of the spray power supply. Special arrangements including double screening of the power supply prevent spurious signals at the a.c. supply frequency appearing across this resistor.

The controller may be used either as a simple spray stabilizer or to stabilize the mean electron gun current. The second mode of operation simplifies changes in generator operating conditions, but is unsatisfactory when working near the upper voltage limit, because a flashover leads to an increase in spray which can cause further flashovers. For the second mode of controller operation its inputs are a direct coupled signal from the gun current, a reference, and an a.c. coupled signal from the spray current, as shown in Fig. 5. This arrangement inhibits fast changes in the spray current, while stabilizing the mean value of the gun current. From the generator stability viewpoint the electron gun and spray stabilizer paths are in parallel. At zero frequency the transmission through the spray control path is much the greater, but with rising frequency this transmission falls in a controlled manner and becomes less than that through the electron gun path before the belt transit time phase shift becomes objectionable. Thus, the complete feedback system is stable.

4. PERFORMANCE

Any particle which passes through the analyser has an energy within 1 part in 1 200 of the value determined by the analyser geometry and applied voltage. Thus it is possible to operate the generator at voltages at which it breaks down occasionally, with some sacrifice of average beam current, but without any loss of accuracy.

The uncertainties in beam energy due to the mechanical construction of the analyser have been estimated by Hunt as less than 5 parts in 10^4. There are many potential sources of error in the determination of the analyser voltage. The more important ones are listed below, with the estimated uncertainties. Voltage of miniature standard cells 1 part in 10^4, reference potential divider 1 in 10^4, precision potentiometer 1 in 10^4, unbalance of standardizing and control galvanometers less than 1 in 10^4, effect of leakage currents on divider ratio 1 in 10^4. Zero drift in galvanometers amounted to 10 V referred to the beam energy over two days, and can be reduced by more frequency zero checks. It is therefore reasonable to assign an accuracy of 1 in 10^3 to the energy of the beam. Periodic check determinations of known nuclear resonances agree to better than 1 part in 10^3, confirming that the analyser power supplies must be stable to at least this accuracy over periods of months. Without the intershield the generator can run for hours without adjustment of the generating voltmeter tracking control, with the tracking meter showing drifts of about ± 2 parts in 10^3. This checks the stability of the generating voltmeter and its associated circuits.

5. CONCLUSIONS

The system described has been very satisfactory for a number of years. Operationally, it is only necessary to set up the required voltage by pressing buttons and then to increase the spray voltage until the machine voltage stabilizes. At the highest voltages the potential division between high voltage terminal and intershield varies and causes difficulties with tracking.

In any new machine having an intershield an auxiliary analyser before the main one and providing a coarse error signal would be worth consideration. Under all normal conditions, however, the equipment described has proved both reliable and accurate.

ACKNOWLEDGEMENTS

The authors are indebted to many of their colleagues for assistance received during the progress of the work, in particular Mr. D. R. Chick and Mr. D. P. R. Petrie were in charge of the generator programme and responsible for many of the concepts described in this work. Dr. S. E. Hunt was responsible for the electrostatic analyser and precision potential dividers and Mr. I Collip carried out much of the experimental work. Thanks are also due to Dr. T. E. Allibone, Director of the Research Laboratory, Associated Electrical Industries, for permission to publish this paper.

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APPENDIX I. THE TRANSIENT RESPONSE OF GENERATING VOLTMETER

The analysis is given for a perfectly balanced push-pr circuit using an amplifier with capacity feedback as describ by Fortescue and Hall. It is assumed that the amplifie linear, of wide band width and low output impedance. T effects of departures from the ideal conditions assumed the analysis are discussed later. The equivalent circuit as shown in Fig. 8 where:

C_{T1}, C_{T2} are the instantaneous capacities from the hi voltage electrode to the two sets of stator plates.

C_2 is the capacity from either set of stator plates to eart including wiring and amplifier capacity.

C_1, C_1 are the feedback capacities.

C_3 is the capacity between the two sets of stator plates.

R, R are the amplifier grid resistances.

V_T is the high voltage electrode potential.

V_{g1}, V_{g2} are the voltages at the two input points of the pus pull amplifier.

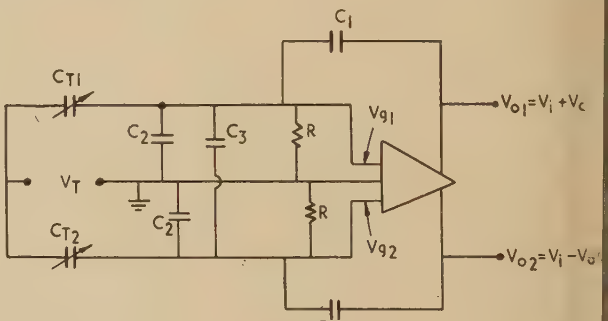

Fig. 8. Equivalent circuit of generating voltmeter and generating voltmeter amplifier

The amplifier has gains of M and rM for antiphase a inphase signals respectively so that one may define inpha and antiphase outputs V_i and V_a by the relationships:

$$V_a = \tfrac{1}{2}(V_{01} - V_{02}) = -\tfrac{1}{2}M(V_{g1} - V_{g2})$$

$$V_i = \tfrac{1}{2}(V_{01} + V_{02}) = -\tfrac{1}{2}\, rM(V_{g1} + V_{g2})$$

If it is assumed that at time $t = 0$, all potentials are ze then, equating the flow of charge to and from one ampli input point:

$$V_T C_{T1} + (V_i + V_a)C_1 + V_{g2}C_3 = \\ = V_{g1}(C_1 + C_2 + C_3 + C_{T1}) + \frac{1}{R}\int_0^t V_{g1}dt$$

$V_{g1}C_{T1}$ may be neglected in comparison with $V_T C$ From equation (3) and a similar equation for the ot plifier input point, and using equations (1) and (2) to minate V_{g1}, V_{g2}, one obtains:

$$_T\frac{(C_{T1}-C_{T2})}{2}=-\left[C_1+\frac{C_1+C_2+2C_3}{M}+\frac{1}{MR}D^{-1}\right]V_a \tag{4}$$

d

$$V_T\frac{(C_{T1}+C_{T2})}{2}=-\left[C_1+\frac{C_1+C_2}{rM}+\frac{1}{rMR}D^{-1}\right]V_i \tag{5}$$

ere D is the differential operator.

Assume a step function in V_T at time $t=0$. Further, sume that C_{T1}, C_{T2} can each be expressed as the sum of a nstant term and a sinusoidally varying term. Thus:

$$C_{T1}=C_{T0}+C_T\cos(\omega t+\phi) \tag{6}$$

$$C_{T2}=C_{T0}-C_T\cos(\omega t+\phi) \tag{7}$$

e phase angle ϕ is necessary because one must consider at the step function in V_T can be applied at any phase ative to the variation of C_{T1}, C_{T2}, and it has been assumed at the step function is applied at $t=0$. Then:

$$.\,u(t)C_T\cos(\omega t+\phi)=-$$

$$-\left(C_1+\frac{C_1+C_2+2C_3}{M}+\frac{1}{MR}D^{-1}\right)V_a \tag{8}$$

d

$$V_T.u(t)C_{T0}=-[C_1+(C_1+C_2)/rM+(1/rMR)D^{-1}]V_i \tag{9}$$

ere $u(t)$ is the unit step function. The solutions are:

$$=-V_T\frac{C_T}{C_1+(C_1+C_2+2C_3)/M}\,\frac{1}{\sqrt{[1+1/(\omega T_a)^2]}}$$

$$\times\left[\cos\left(\omega t+\phi+\tan^{-1}\frac{1}{\omega T_a}\right)+\right.$$

$$\left.+\frac{1}{\omega T_a}\cdot e^{-t/T_a}\sin\left(\phi+\tan^{-1}\frac{1}{\omega T_a}\right)\right]$$

$$V_i=-V_T\cdot\frac{C_{T0}}{C_1+C_1+C_2/rM}e^{-tT_i}$$

ere

$$T_a=R[(M+1)C_1+C_2+2C_3]$$

$$T_i=R[(rM+1)C_1+C_2]$$

The antiphase output consists of a sinusoidal term, with amplitude proportional to V_T, plus an exponential term ich will be small if $\omega T_a \gg 1$. If the antiphase output is ctified and filtered, the response of the filter being essentially at of a single ($R-C$) low pass circuit of time constant T_f, output will be of the form $kV_T(1-e^{-t/T_f})$. The phase output in response to a step function input consists a sudden change of potential, followed by an exponential urn to zero with time constant T_i.

If the filter time constant T_f is made equal to T_i, and if output of the filter is added to the inphase output of the plifier, the relative gains being suitably adjusted, the ponential terms cancel, and the total output is just kV_T, the variations of the input are reproduced perfectly.

If M is made large so that $MC_1 \gg (C_1+C_2+2C_3)$ and $T_a \simeq \omega MRC_1 \gg 1$,

$$V_a \simeq -V_T\cdot\frac{C_T}{C_1}\cos(\omega t+\phi)$$

d so the calibration of the instrument is to a first order lependent of everything except C_T, which is a function of geometry of the generating voltmeter itself and C_1, the feedback capacity. The feature that the calibration is independent of the generating voltmeter rotor speed is particularly desirable. To provide good filtering of the detector output, T_f should be made large. As T_i has to be equal to T_f, this requires $rM \gg 1$. Under these conditions, $T_i \simeq rMC_1R$, and

$$V_i \simeq -V_T\cdot\frac{C_{T0}}{C_1}e^{-t/T_i}$$

Before mixing with the filtered detector output, this signal should be attenuated in the ratio of the detector output to the peak detector input signal.

This idealized system has perfect response and it is now necessary to investigate practical imperfections.

First, the band width of the instrument is limited. The response time will probably be a few microseconds, which is enormously less than that of a conventional generating voltmeter, and if need be the response time could be made a fraction of a microsecond.

If the two sides of the push-pull circuit are not perfectly balanced, additional exponential terms are introduced into the antiphase output, and a sinusoidal term is introduced in the inphase output. The amplitudes of these terms relative to the principal ones are of the same order as the fractional unbalances which cause them. The sinusoidal term in the inphase output may be eliminated by taking this output from a tapping on a potential divider connected between the two amplifier output points and adjusting the tapping point so that the ripple vanishes (see Fig. 6). It is useful to have a small amount of quadrature adjustment available. The exponential terms in the antiphase output are likely to be less important. Their effect may be reduced by arranging that the circuit coupling the antiphase output to the detector contains one or more high pass circuits with time constants chosen so as to give negligible attenuation at the generating voltmeter carrier frequency, but to be appreciably less than T_a and T_i.

The variation of the capacities, C_{T1}, C_{T2} with time may not follow the simple constant plus sinusoid law which has been assumed, but may include harmonics of the sinusoid. Odd harmonics will modify the shape of the waveform fed to the detector, which will not matter, and will cancel in the inphase output. Even harmonics, which represent variations in the total capacity $(C_{T1}+C_{T2})$ from the high voltage electrode to the generating voltmeter stator plates as a function of the rotor position, will add at the inphase output. This produces an effect equivalent to a ripple at twice the carrier frequency of the generating voltmeter on the voltage to be measured. In a practical case, this ripple had a frequency of 800 c/s and a peak to peak value of 0·2% of the d.c. level. The second harmonic term may be cancelled by more second harmonic signal obtained from the full wave detector circuit. It was found experimentally that although the second harmonic terms cancelled, the fourth harmonics added, and an improvement of 2 : 1 was all that could be obtained. Non-linearity of the amplifiers could give a similar effect, but as the best adjustment of the compensating circuit appeared to be independent of the generator voltage it is evident that this was a minor effect in the case investigated.

If the generating voltmeter rotor and stator are not perfectly symmetrical, output signals at the generating voltmeter rotor speed may be produced. In the case studied this effect gave an output signal at very nearly 50 c/s equivalent to a ripple on the high voltage of peak to peak value 0·1% of the d.c. level. Thus if in any particular application there is no objection to ripple voltages with peak to peak values of about 0·2% of the mean output voltage, this method of using a generating voltmeter provides a system giving a level response from d.c. to a frequency determined by the high frequency response of the amplifiers used. If, however, such ripple voltages are objectionable the high frequency response must be limited to reduce the ripple voltage to an acceptable value, but the speed of response is still better than that of a conventional generating voltmeter.

Smith(12) has also described a method of obtaining a fa response from a generating voltmeter. The two metho appear to be comparable in respect of response periods a circuit complexity. Smith's method appears to be inferi by a factor of about 10 in respect of residual ripple volta at the output, but in some applications his avoidance having to match the characteristics of low and high frequen channels would be an advantage.

The Leon tube: An instrument for measuring flow speeds in wat

By J. F. Kemp, M.Eng., National Mechanical Engineering Research Institute, Pretoria, South Africa

[*Paper received* 11 *February*, 1957]

A description is given of the construction and performance characteristics of an instrument which is capable of measuring flow speeds in water "at a point" over a range of 1 to 14 ft/s. The accuracy at 1 ft/s is approximately 1½% and improves rapidly with increasing speed. The Leon tube is of robust and compact construction and is, in effect, a combination of a differential pressure tube and a differential liquid manometer. The pressure factor of the tube, which is a function of Reynolds number, is most readily determined in a wind tunnel. The instrument has proved to be particularly suitable for the performance of velocity traverses in open channels.

During a recent investigation by this Institute into the problem of water seepage from the surface to the underground workings in one of the Transvaal gold mines, an instrument was required for measuring flow rates at a number of stations on the surface as well as underground. At these stations the water flowed in small, irregular canals, and conditions were such that flow rates could only be determined by means of velocity traverses. For this purpose the instrument was required to be capable of measuring flow speeds as low as 1 ft/s "at a point," in addition to being robust and easy to manipulate.

Existing types of flow instrument were considered but were all found to fail in one or more of the requirements stipulated above. The Leon tube, so called after one of the author's colleagues, was therefore developed, and was used successfully in the investigation.

OPERATING PRINCIPLES

The schematic sketch (Fig. 1) serves to elucidate the working principles of the new instrument. The two connecting tubes A and B of a differential pressure probe a, b are transparent and function as the vertical limbs of an inverted U-tube manometer, the top of which is connected to a container C *via* a three-way tap D.

For the measurement of low speeds, container C is filled with a liquid the density of which is smaller than that of water. Probe a, b is immersed in the flow, so that the pressure holes are adequately covered by water. Tap D is then opened to allow the liquid to fill both limbs as well as the probe. As soon as the liquid is observed to flow freely from the pressure holes, suction is applied orally at flexible tube E, thus drawing the liquid back toward C until water appears in the manometer limbs. When the menisci in A and B reach a position about midway between the probe and the top of the inverted U-tube, tap D is turned to the setting where C is shut off, while A and B remain interconnected.

The instrument will now be ready for use. The flow sp v, in feet per second, is given by the formula

$$v = [2g(1 - S)h/K]^{\frac{1}{2}}$$

where g = acceleration of gravity (ft/s^2),
S = specific gravity of the liquid in C,
h = differential pressure head (ft) and
K = probe factor defined by the equation

$$\Delta p = K(\tfrac{1}{2}\rho v^2)$$

in which Δp represents the differential pressure generated the probe at the corresponding dynamic head $\frac{1}{2}\rho v^2$ of flow.

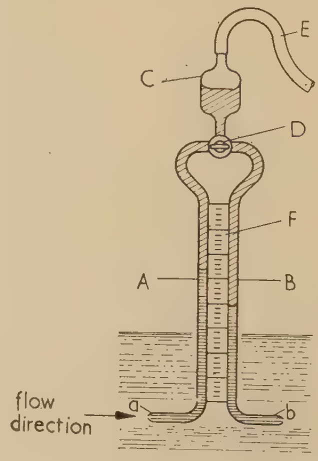

Fig. 1. Schematic sketch of the Leon tube

Factor K depends on the geometry of the probe and on flow Reynolds number, and has to be determined exp mentally.

The differential pressure head h is measured on a suita scale F (Fig. 1). If so required, tap D may be set in suc sition as to block all passages leading from it, thus allowing : tube to be lifted in, or removed from, the current in order at *h* may be noted at leisure.

Utilizing the inverted U-tube as a differential liquid mano-:ter in the manner described above, the maximum speed at can be measured will be governed by the specific gravity of the liquid in container *C*, and by the effective length of : manometer limbs. For the measurement of higher eeds, *C* is drained, and air is used in lieu of the liquid. The w-speed *v*, in feet per second, will now be given by the rmula

$$v = (2gh/K)^{\frac{1}{2}} \tag{3}$$

in this case representing the differential pressure head in et of water column.

Manipulation of the instrument will remain as above, cept for the fact that the tube may not be withdrawn from position in the flow prior to noting a reading on the scale. he different lengths of air column in the inverted U-tube ll not expand equally under the weight of the water columns en the tube is lifted from the flow.)

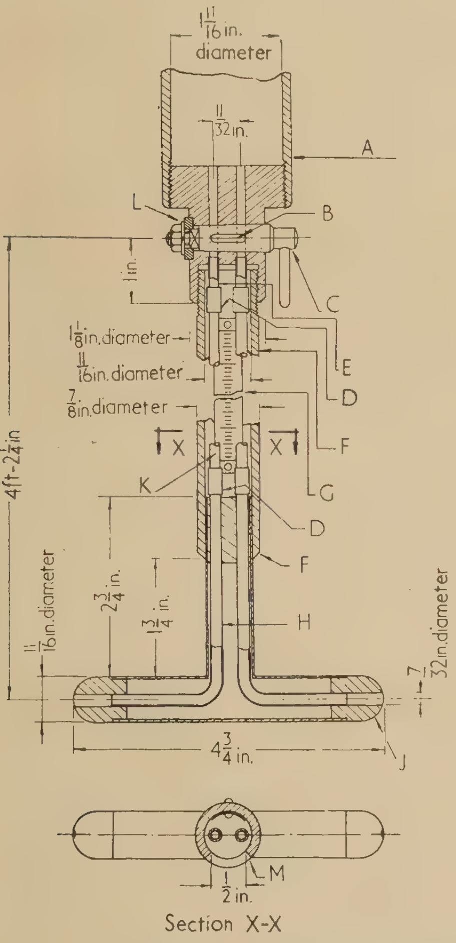

Fig. 2. Constructional details of the prototype

A, Perspex container; *B*, recess milled to $\frac{1}{8}$ in. depth; *C*, body of tap tapered one part in thirty, $\frac{3}{8}$ in. diameter at small end; *D*, plastic connecting tubes; *E*, connecting nipples, $\frac{1}{8}$ in. bore copper tubes; *F*, galvanized steel tube, $\frac{7}{8}$ in. outer diameter, $\frac{11}{16}$ in. bore; *G*, steel tape riveted to galvanized steel tube; *H*, copper tubes, $\frac{1}{8}$ in. bore; *J*, hemispherical nose; *K*, glass tubes, 4 mm bore; *L*, spring washer; *M*, galvanized tube slotted over a length of 43 in.

DESIGN AND CONSTRUCTION OF THE PROTOTYPE

The construction of the differential pressure probe and of the tap assembly is illustrated in Fig. 2. Two glass tubes of 4 mm bore are used for the limbs of the manometer, these being connected by short lengths of plastic tubing to the nipples on the probe and tap components. The glass tubes are sheathed in a protective tube of galvanized steel, the one side of which is slotted to expose the glass tubes. A steel tape, riveted to the inside of the steel tube, serves as manometer scale. The effective length is 43 in. The liquid container, which screws on the tap housing, is made of a $1\frac{1}{16}$ in. bore Perspex tube, about 6 in. long.

A number of possibilities suggest themselves regarding the choice of liquid to use with the tube. Any low viscosity paraffin or oil is suitable, provided its colour presents a distinctive contrast with water at the interface of the two liquids. In the prototype a petrol-oil mixture was used in the ratio 5 to 1, the specific gravity being 0·771.

PERFORMANCE CHARACTERISTICS OF THE INSTRUMENT

When used in conjunction with the petrol-oil mixture, the instrument has an effective range of approximately 1 to 6 ft/s, the lower value corresponding to a differential pressure head slightly higher than 1 in. As this head can be read from the scale with an accuracy of about $\frac{1}{32}$ in, the accuracy of the instrument at 1 ft/s amounts to about $1\frac{1}{2}$%. When air is used instead of the liquid, an overlapping range of speeds extending from 2 to 14 ft/s becomes available.

A notable feature of the Leon tube, whether used with a liquid or with air, is its quick response. This feature makes it particularly suitable for the performance of velocity traverses in open channels.

Calibration of the tube was performed in a 24 in. wind-tunnel over a range of Reynolds numbers (based on probe diameter) of 2300 to 25 000. The procedure was briefly as follows: the differential pressure Δp of a calibrated N.P.L. type Pitot-static tube and of the Leon tube were in turn determined as a function of the propeller speed of the tunnel, the latter being measured very accurately by means of a tachoscope, that is, a combined stopwatch and revolution counter. The *K*-factor of the Leon tube K_L at a given air speed, or propeller speed, can be calculated from the formula

$$K_L = K_S(\Delta p_L/\Delta p_S) \tag{4}$$

where suffices *L* and *S* denote the Leon and standard tubes respectively.

Fig. 3 depicts the calibration curve thus obtained. The

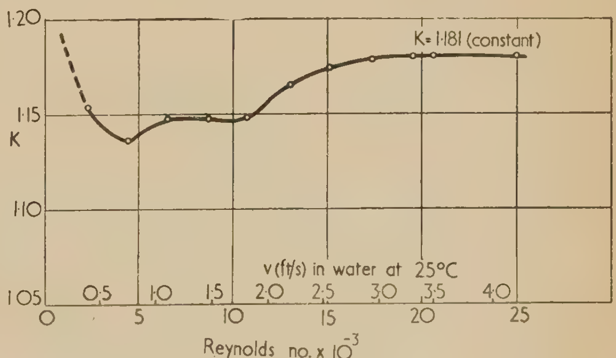

Fig. 3. Calibration curve of the prototype

K-factor of the tube becomes immune to scale effect at Reynolds numbers above 19 000 where the corresponding flow speed in water at 25° C is about 3·2 ft/s.

A further characteristic of the instrument that may be of interest, is its directional response curve, as presented in Fig. 4. This curve pertains to a moderately high flow velocity of 4 ft/s in water (the corresponding Reynolds number being 23 750), and illustrates the variation of function $(\Delta P_\theta/\Delta P_0)^{\frac{1}{2}}$ with angle of yaw θ; ΔP_θ and ΔP_0 indicate differential pressures at angles θ and zero respectively. By plotting the square root of their quotient as ordinates in the graph, it is possible to deduce directly the magnitude of errors that would be incurred in speed measurements if the probe w not properly alined to face in the direction of flow. It clear that a misalinement of up to 5° will be of no accou even when high accuracy of measurement is required. If accuracy of 5% can be tolerated, the tube becomes om directional up to angles of 25°.

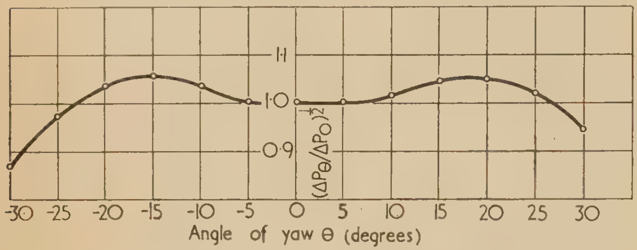

Fig. 4. Directional response curve of the prototype

In conclusion it may be mentioned that an attempt w originally made to convert an N.P.L.-pattern Pitot-sta tube to function in a manner similar to the Leon tube. T motives were to obtain a *K*-factor closer to unity, and p ticularly to minimize scale effect in the operational range the tube. The experiment proved unsuccessful, however, d mainly to air entrainment from the static-pressure part of tube, and to the continual presence of suspended wa droplets in the oil column of the static-pressure limb of inverted U-tube.

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The adjustment of optical systems

By W. S. Blaschke, Taylor, Taylor and Hobson Ltd., Leicester

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The most efficient method of adjusting an optical system to satisfy prescribed Gaussian conditions is given. Additional formulae relate such adjustments to errors present in the components of the system.

If a series of lens elements forming an optical system with a given function are assembled, adjustments in separation have generally to be made to allow for errors in the components. This could be done by taking the components comprising the essential powers of the system and adjusting them until each has the right focal length. They could then be combined with designed separations and the system would be as intended, except for changes in nodal position and nodal thicknesses due to the adjustments themselves. The most serious drawback of this method, however, is the comparatively large separation changes which are often required to reset the focal length. Changes in aberrations can thus easily become serious. It is clearly not the best mode of adjustment.

The aim of the present treatment is to find quite generally from design data and given errors in components, or in the assembled system, the minimum movements necessary to restore the correct function of the system. The function of the system is here defined not from the combined focal length and total nodal thickness, but by the total physical object-to-image throw and magnification under the intended conditions of use. Two degrees of freedom will evidently be sufficient for the adjustment. A third is added to satisfy a minimum condition. The problem is solved by differential changes in Gaussian conditions and leads to first order values of the adjusting movements. The ratio of movement thus established is fundamental to the adjustment. In practi the compensation for quite considerable errors in the syst is possible by one or two iterations with movements in same ratio.

$$\underset{0}{\Big|}\;\underset{\Sigma}{}\;L_1\begin{pmatrix}K_1\\M_1\end{pmatrix}S_1\begin{pmatrix}K_2\\M_2\end{pmatrix}S_2\begin{pmatrix}K_3\\M_3\end{pmatrix}\;L_3'\;\underset{0'}{\Big|}$$

Σ is an optical system divided into three arbitrarily chos parts. They have powers K_1, K_2, K_3 and magnificati (transverse) M_1, M_2, M_3. The total magnification is M. T total physical throw from 0 to 0′ is T. L_1 is the initial (sh conjugate) measured from the first lens surface (with us sign convention). S_1, S_2 are physical separations of co ponent parts. Capital letters are used for these quanti in the system and small letters for increments in them.

The Gaussian planes at 0 and 0′ are the fixed refere frame and L_1, S_1, S_2 are to be changed by l_1, s_1, s_2 so as restore the correct throw and magnification as well satisfying (Case I).

$$wl_1^2 + w_1s_1^2 + w_2s_2^2 = \text{min.}$$

where w, w_1, w_2 are proportional to the change of aberrati with l_1, s_1 and s_2 respectively and weight these accordingly.

If M_3 is very large, which is frequently the case, the syst onsidered reversed and equation (1) is replaced (Case II)

$$wl_3'^2 + w_1s_1^2 + w_2s_2^2 = \text{min.} \tag{1a}$$

being now the short conjugate, and s_1, s_2 the same as before. We use the following obvious expressions for the partial erential coefficients.

$$\partial M/\partial L = -M^2K \tag{2a}$$

$$\partial T/\partial L = M^2 - 1 \tag{2b}$$

er in deriving equations (12) and (13) we will also use

$$\left(\frac{\partial T}{\partial K}\right)_L = -\left(\frac{M-1}{K}\right)^2 \tag{3a}$$

$$\left(\frac{\partial M}{\partial K}\right)_L = M(M-1)/K \tag{3b}$$

f now we group elements in the system subsequent to the ange of separation we have for the total change in throw

$$t = al_1 + a_1s_1 + a_2s_2 \tag{4}$$

ere

$$= M^2 - 1,\quad a_1 = -[(M_2M_3)^2 - 1],\quad a_2 = -[M_3^2 - 1] \tag{4a}$$

obtain an expression for the change in magnification in ms of M_1, M_2, M_3, K_1, K_2, K_3 we group initially elements and 3 and have

$$m = M_3m_{12} + M_{12}(\partial M_3/\partial L_3)(t_{12} - s_2 - s_1 + l_1) \tag{5}$$

ere

$$m_{12} = M_2(\partial M_1/\partial L_1)l_1 + M_1(\partial M_2/\partial L_2)(t_1 - s_1 + l_1) \tag{5a}$$

bstituting and using equations (2a) and (4) we have

$$m = bl_1 + b_1s_1 + b_2s_2 \tag{6}$$

ere

$$\left.\begin{aligned} b &= -M[(M_1K_1) + M_1^2(M_2K_2) + M_1^2M_2^2(M_3K_3)] \\ b_1 &= M[M_2K_2) + M_2^2(M_3K_3)] \\ b_2 &= MM_3K_3 \end{aligned}\right\} \tag{6a}$$

e introduce equation (1) and have (Case I)

$$wl_1 + w_1s_1(\partial s_1/\partial l_1) + w_2s_2(\partial s_2/\partial l_1) = 0 \tag{7}$$

fferentiating equations (4) and (6) with respect to l_1

$$a + a_1(\partial s_1/\partial l_1) + a_2(\partial s_2/\partial l_1) = 0 \tag{8}$$

$$b + b_1(\partial s_1/\partial l_1) + b_2(\partial s_2/\partial l_1) = 0 \tag{9}$$

d eliminating $\partial s_1/\partial l_1$ and $\partial s_2/\partial l_1$ from equations (8) and (9) have, from equation (7), the additional equation

$$cwl_1 + c_1w_1s_1 + c_2w_2s_2 = 0$$

ere

$$c = \begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix},\quad -c_1 = \begin{vmatrix} a & a_2 \\ b & b_2 \end{vmatrix},\quad c_2 = \begin{vmatrix} a & a_1 \\ b & b_1 \end{vmatrix} \tag{10}$$

A is then the matrix formed from equation (4), (6) and (10) have the required result in the form

$$\begin{pmatrix} l_1 \\ s_1 \\ s_2 \end{pmatrix} = A^{-1}\begin{pmatrix} t \\ m \\ 0 \end{pmatrix} \tag{11}$$

ere only the first two columns of A^{-1} are needed.

If the system has to be taken reversed (Case II) we note firstly that

$$T = L_3' + S_1 + S_2 - L_1 = \text{constant}$$

and hence $\quad l_3'^2 = (s_1 + s_2 - l_1)^2$

Using this in condition (1a) gives

$$w_1s_1\frac{\partial s_1}{\partial l_1} + w_2s_2\frac{\partial s_2}{\partial l_1} + w(s_1 + s_2 - l_1)\left(\frac{\partial s_1}{\partial l_1} + \frac{\partial s_2}{\partial l_1} - 1\right) = 0$$

Proceeding as before we have corresponding to equation (10) the additional equation

$$dl_1 + d_1s_1 + d_2s_2 = 0 \tag{10a}$$

where

$$d = w(c - c_1 - c_2),\quad d_1 = w_1c_1 - w(c - c_1 - c_2),$$
$$d_2 = w_2c_2 - w(c - c_1 - c_2).$$

$$\begin{pmatrix} l_1 \\ s_1 \\ s_2 \end{pmatrix} = B^{-1}\begin{pmatrix} t \\ m \\ 0 \end{pmatrix} \tag{11a}$$

where $\boldsymbol{B}$ is the matrix formed from equations (4), (6) and (10a), and is the required result for the system taken reversed. The extention to more than three movements is obvious, but of little practical value.

The vector $\begin{pmatrix} t \\ m \\ 0 \end{pmatrix}$ may be given from measurement on the system assembled to designed separations. Alternatively it may be obtained from measured or expected errors in focal lengths of the separate lens elements comprising the system. For the latter the following relations are useful. [They are derived in the same way as equation (6).]

$$t = -\sum_{r=1}^{n}(1 - M_r)^2(M_n\,.\,M_{n-1}\ldots M_r)^2\frac{k_r}{(M_rK_r)^2} \tag{12}$$

$$\begin{aligned} m = M\Bigg\{\sum_{r=1}^{n}(M_r - 1)\frac{k_r}{K_r} + \sum_{r=1}^{n-1}(M_r - 1)^2\frac{k_r}{K_r^2} \\ [(M_{r+1}K_{r+1}) + M_{r+1}^2(M_{r+2}K_{r+2}) + \ldots + \\ + M_{r+1}^2M_{r+2}^2\ldots(M_nK_n)]\Bigg\} \end{aligned} \tag{13}$$

n being the number of lens elements considered and k_r the error in a particular power K_r.

Thus the adjustments required may be directly obtained from the tolerances imposed on the manufacture of the separate components.

We conclude that the correct procedure for adjustment is to reiterate with the inverse matrices A^{-1} or B^{-1}, as the case may be. One or two iterations will give the required movements even where considerable errors are present. In practice it is easier to take the first multiplication by A^{-1} or B^{-1} as establishing the required adjustment plus the ratio of any subsequent small increments to the movements which may be necessary. Thus no further calculation is needed during the process of adjustment.

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New infra-red detectors using indium antimonide

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[*Paper first received* 10 *January, and in final form* 20 *March*, 1957]

The paper describes the properties of InSb detectors, at room temperature, using the photoconductive process, and experimental work on sensitive *p–n* junction detectors, cooled to 90° K, used as photo-voltaic cells.

INTRODUCTION

Photo-effects in InSb have been reported extending to wavelengths around 7·5 μ at room temperature,(1, 2) and sensitivity in InSb *p–n* junctions has been reported extending to wavelengths around 5·8 μ(3) The purpose of this paper is to describe in more detail the properties of room temperature InSb detectors using the photoconductive process, and to describe experimental work on sensitive *p–n* junctions cooled to 90° K. In a recent note, Hilsum and Ross,(4) have described room temperature detectors using the photomagnetic effect.

ROOM TEMPERATURE PHOTOCONDUCTIVE DETECTORS

These take the form of thin strips of InSb, of area about 8 × 0·5 mm which have leads soldered at each end, and which are mounted on a varnished metal support. The starting material is single crystal InSb prepared by the pulling technique from previously zone-refined compound. The strips are prepared by first slicing the crystal using a wire-saw, grinding the slices to dimensions 8 × 1 × 0·2 mm followed by a final electrolytic polish.

A suitable polarizing voltage is applied across the strip, which is illuminated with modulated radiation. The resultant changes in resistance of the strip are then observed as an alternating photoconductive current. The resistances are typically between 50 and 500 Ω and in order to make use of the full signal/noise ratio developed in the detector it is customary to use a step-up transformer to increase the noise voltage from the detector to a level greater than the noise in the input stage of a conventional valve amplifier.

The performance of one such detector, operated with an applied voltage of 2·5 V, is shown as a graph of minimum detectable energy* (m.d.e.) against wavelength in Fig. 1.

The noise in the detector which limits the sensitivity is substantially Johnson noise, at least for low applied voltages. For higher voltages, Joule heating of the detector limits its sensitivity, the sensitivity falling by about 2% for each degree rise in temperature. It will be seen from Fig. 1 that the detector roughly responds equally to equal numbers of photons incident upon it anywhere within its spectral range.

Measurements of carrier lifetime in this material(2) suggest that the response time should be about $4 \cdot 10^{-8}$ s. Observations of the signal obtained when the detector was illuminated by a pulsed spark having a rise time of $2 \cdot 10^{-7}$ s were indistinguishable from the signals obtained from the same source using a photomultiplier tube. This is taken as evidence that the response time is at least less than $2 \cdot 10^{-7}$ s.

The sensitivity of this detector is one to two orders of magnitude less than that of good radiation thermopil operated at frequencies of about 5 c/s. However, in ma applications the extremely fast response (20 Mc/s) may mo than outweigh its lower sensitivity. For any experime where high sampling rates are desired, or where transie phenomena are to be observed, these are the most suitab

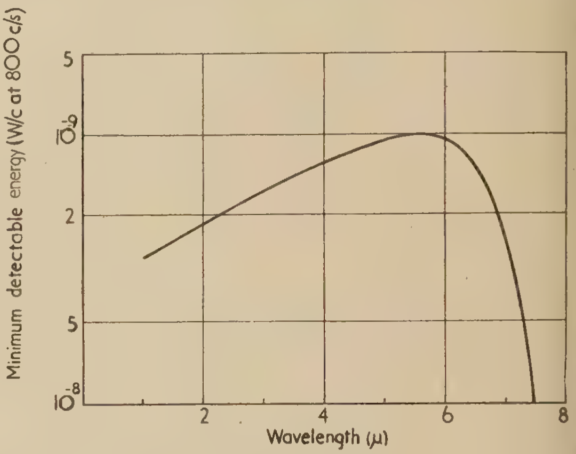

Fig. 1. InSb photoconductive detector, operating at 250° K

Sensitive area 6 × 0·25 mm; applied d.c. voltage = 2·5 V.

room temperature detectors for wavelengths beyond the Pb limit of ∼3μ(5). Transistor amplifiers could be used, workin directly from the strip resistance of say, 100 Ω, with qui small loss in signal/noise, at modulation frequencies in exce of 1–2 kc/s.

InSb detectors have an additional advantage over mo existing photoconductive cells, other than chemically deposit PbS cells (see, for example, Milner and Watts(5)), in that th are stable in air over periods of, at least, many months a they require no envelope. It is thus a simple matter to u detector strips of the dimensions described to build a desired array of detectors to match any optical proble From the point of view of flexibility of design, photoconducti detectors have this advantage over photomagnetic detecto since in order to maintain adequate magnetic fields, ea photomagnetic detector requires a separate polarizing magn

COOLED P–N JUNCTION DETECTORS

Essentially similar devices to that previously reported Mitchell and co-workers(3) have been prepared and the properties will be described since they seem potentially usef infra-red detectors.

The InSb junctions were prepared by first melting mater of known excess carrier concentration on to the end of le crystal seed with excess carriers of the opposite type fewer in number. On reversing the direction of motion he freezing plane, a single crystal is formed containing the ction. Both seed and melt were held in a silica boat ted with carbon black. The crystal was then sliced so t each slice contained the junction as shown in Fig. 2. dimensions are roughly as shown, after a final electrolytic n.

---

* The m.d.e. is here defined as that amount of radiation incident upon the detector which will give a signal/noise ratio of unity, unit bandwidth being assumed in the electronic circuit. It will be quoted as watts/cycle.

Iost of the measurements were made with the slice mounted a demountable metal Dewar system arranged so that the ction could be illuminated either with a uniform flux m a tungsten lamp, or with a micro-illuminator described ewhere.$^{(6)}$ Whilst the junction temperature was nominally ° K, it is possible that it was in fact some 10° higher than this. Some slices have been mounted in conventional glass Dewar vessels as used for PbTe cells.$^{(7)}$

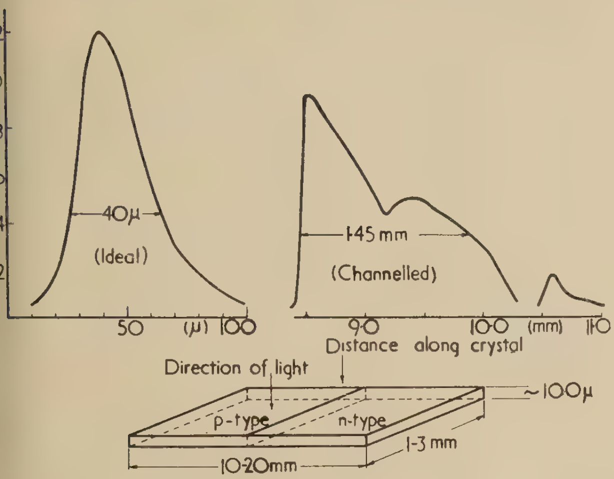

Fig. 2. Distribution of sensitivity on p–n junctions

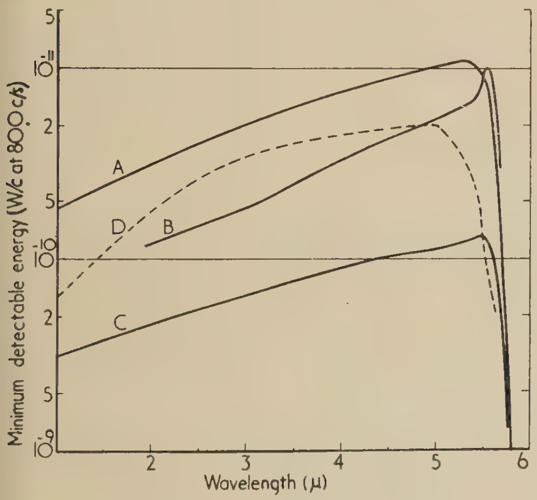

Fig. 3. Graphs of m.d.e. against wavelength for three InSb p–n junctions compared with typical PbTe cell

nSb p–n junctions: curve *A*, area = 3·5 × 0·040 mm = = 0·14 mm²; curve *B*, area = 1 × 0·055 mm = 0·055 mm²; urve *C*, area = 0·7 × 0·175 mm = 0·12 mm².
PbTe cell: curve *D*: assumed area = 0·1 mm².

The junctions were used as photo-voltaic cells and measurements have been made of the m.d.e. as a function of wavelength, and the distribution of sensitivity across the surface in the neighbourhood of the junction. Some showed a slow variation of sensitivity with time; the cause of this variation is not understood, but may be associated with the condensation of residual vapours in the Dewar cell.

In Fig. 3, graphs of m.d.e. against wavelength are shown for three of these detectors and compared with a typical PbTe cell,$^{(7)}$ assuming that the m.d.e. of a PbTe cell is proportional to the square root of its sensitive area. Assuming this proportionality, the m.d.e. for the PbTe cell quoted by Moss$^{(8)}$ is an order of magnitude less than that shown in Fig. 3.

The area quoted for a *p–n* junction cell is defined as the specimen width multiplied by that distance along the surface within which illumination with a fine light spot produces a signal greater than e^{-1} times the maximum signal. For the case of an ideal junction, this distance is the sum of the carrier diffusion lengths on either side.$^{(9)}$ In practice this simple pattern may be modified by surface channels.$^{(10)}$ Distributions have been observed suggesting this type of channel, and also in some cases double peaks of unexplained origin have been found. Two typical distributions are given in Fig. 2.

These detectors have resistances of about 1 to 10 kΩ as compared with the 1 to 100 MΩ associated with PbTe cells, a much more convenient impedance from the point of view of associated electronic circuits. The noise observed is in general up to ten times greater than the expected Johnson noise. The source of this excess noise has not been studied, but it has been found to increase rapidly with the application of reverse bias to the junction.

The response time of these junction devices is again very short, at most $2 \cdot 10^{-7}$ s as determined from the pulsed spark method.

ACKNOWLEDGEMENTS

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The plotting of strain-hysteresis loops

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The difficulty of measuring the small departures from linearity in the extension of steel specimens subjected to cyclic tensile loading was overcome in this case by comparing the extension of the specimen with that of a member of which the stress-strain curve is, by comparison with the specimen, linear. The scatter of the results obtained with this apparatus indicates that the accuracy of observation of a single strain-hysteresis loop is 4%. The effect was investigated of increasing the direct load while keeping the amplitude of alternating load constant. Stresses were confined to the normal working range.

This paper describes an apparatus for measuring the loss of energy in a tensile specimen which is subjected to cyclic loading. The stress-strain curve for this type of loading is a loop and the area of the loop is equal to the energy dissipated in one loading cycle. The apparatus to be described is designed to plot the loop so that its area may be measured. The paper contains an account of the results obtained on mild steel specimens.

Fig. 1 represents a stress-strain loop. For metals the intercept *AB* which the loop makes on a vertical line is very small compared with the intercept *CA* between the axis and the loop. If the loop is drawn with the strain scale greatly magnified, in order to make the distance *AB* measurable, then the distance *CA* becomes impracticably large. The principle of the apparatus which is to be described is that an additional line *OX* is introduced into the diagram which serves as an oblique axis. The apparatus plots, on rectangular co-ordinates, a loop which has ordinates *AY* and *BY*; this loop may be plotted with *AB* suitably magnified.

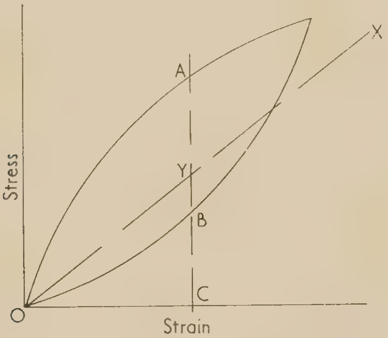

Fig. 1. Stress-strain loop

The apparatus must produce the straight line *OX* and the loop. The two signals in this case are voltages, obtained from a bridge which has in adjacent arms capacitor plates fixed to the apparatus for measuring the movements in its members. One of the members has an extension-load curve which is almost linear; this has been attained by designing in such a way that the maximum stress in it is low compared with the stress in the specimen. The bridge circuit performs the necessary subtraction. With the subsequent differenced signal applied to the *Y*-plates of a cathode-ray tube, a loop is obtained by adding on the *X*-plates a signal representing the load on the specimen.

The linear and non-linear elements do not, however, move equally for a given load, and the changes in signal from one extreme to the other of the cycle of loading are thus not equal. In order to carry out the subtraction the slope of *OX* and that of the loop should be nearly equal. This can achieved by placing the capacitors in adjacent arms of unequal-ratio bridge. A transformer bridge is used(1) stray capacitances have no effect on the balance point such a bridge. The bridges and electronic equipment a shown in Fig. 2. Amplifier gains were 10^8 for the sign representing non-linearity and 10^5 for the channel followi the strain-gauge bridge.

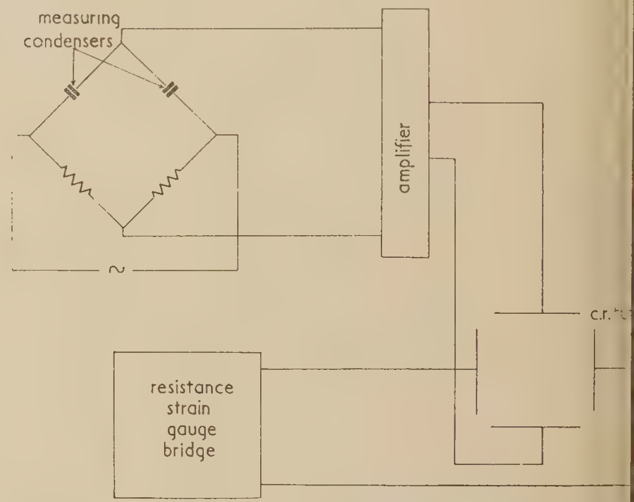

Fig. 2. Bridge circuits

The linear member is a proving ring, shown in Fig. 3, whi was designed using photo-elastic methods in order to ensu that the stress in the lugs is constant. It was made from a ma ganese steel (0·6% carbon, 0·7% manganese, 0·25% silico 0·04% sulphur and phosphorus). The load was applied means of a hydraulic drive, and the ball-and-socket join shown in Fig. 4, were used to transmit the load to eit

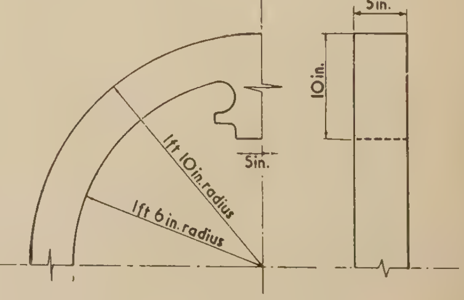

Fig. 3. Proving ring

l of the specimen. An even stress was thus obtained over gauge length, which contained no joint or anchorage. e specimens were rods machined from bars of larger meter to allow of shoulders being left on them to hold the vement gauges. The mechanical equipment was housed a yoke, shown in Fig. 4, measuring 12 × 6 ft, suspended m beams at roof height and insulated from them mechanlly by hard rubber pads, bearing on the cross pins of the pporting stirrups.

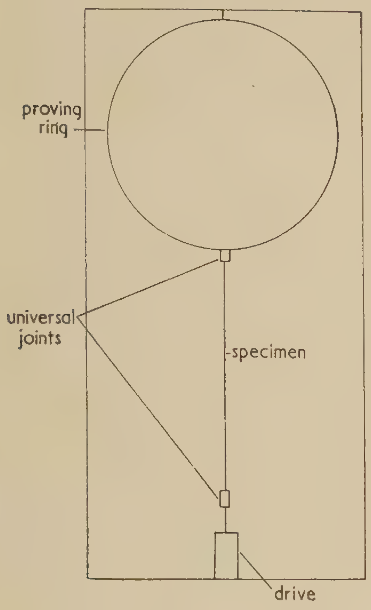

Fig. 4. Yoke

USING THE EQUIPMENT

Two adjustments are necessary for using the equipment: the capacitor plates are set so that they change in spacing equal fractions of their original spacings. This ensures t any output from the bridge is due to non-linearity of the cimen and not to differences in responses of the sets of tes; (2) the voltages on the arms of the bridge have to be usted so that there is zero change in current at the extremes the cycle; the output of the bridge is thus kept small. If spring were linear and the adjustments perfect, the apparatus would give the true shape of the hysteresis loop; if the adjustments were not accurate the shape of the loop would be altered but its area would be unaffected (see Appendix). After making observations, the loop is calibrated in both axes. The force scale is calibrated by marking the X-position of the tracing spot for various loads, with the bridge left in the same condition of balance as during the observations. The scale of non-linear movement of the specimen is calibrated by injecting a small known change of capacitance into the bridge. This change of capacitance corresponds to a calculable change of spacing of the condenser extension-gauges on the specimen. The linearity of the ratios of both voltage output to change in capacitance and to the applied force on the specimen is better than 2%.

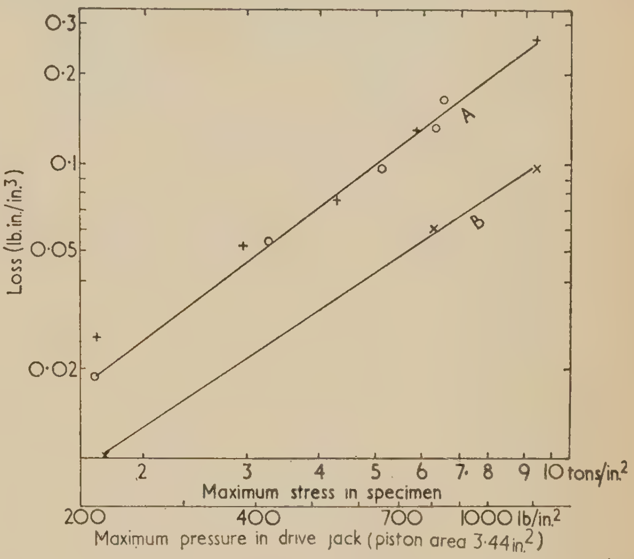

Fig. 5. Loss in steel specimens

A, 60 in. long, + decreasing load, ○ increasing load; B, 21½ in. long; Age: A, 8344–10002 cycles; B, 10082–10748 cycles. Minimum load is zero.

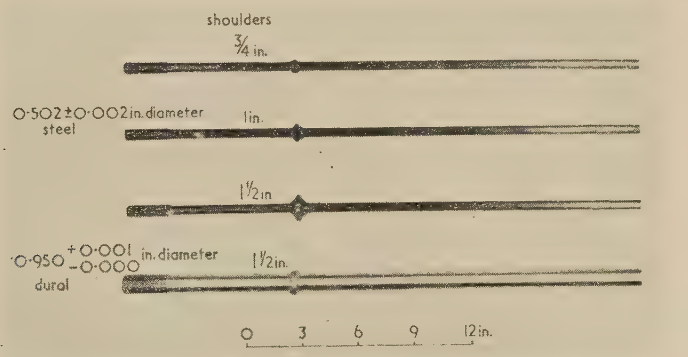

Fig. 6. Specimens showing shoulders

RESULTS

Results obtained from two steel specimens, shown in Fig. 5, agree broadly with published data.(2) The time for one loading cycle is 20–30 s and the loss is independent of period within this range.

Effect of shoulder size. The shoulders on the specimens shown in Fig. 6, were included to prevent high concentrations of stress due to the grips supporting the capacitor plates which were anchored at the gauge ends. It is necessary to design the shoulders so that the loss in them is not a significant proportion of the loss in the specimen. The steel specimens in Fig. 6 which were identical except for the diameters of the shoulders, were tested in the apparatus and it was found that the observed loss varied by less than 5% of the expected total loss in the specimens.

Effect of direct load. The drive equipment was designed to give an infinite variation of direct and superposed alternating loads up to the maximum safe effort from the drive jack. Results of the effect of direct load on the 21 in. steel specimen are shown in Fig. 7. The main trend shown is a decrease of loss with direct load. A previous worker has found an increase.(3) It is possible that the ring loss is affecting this, a point which has yet to be examined. The observed loop drifted at times in the direction of specimen deflexion. The electronic circuit was checked and found to be stable.

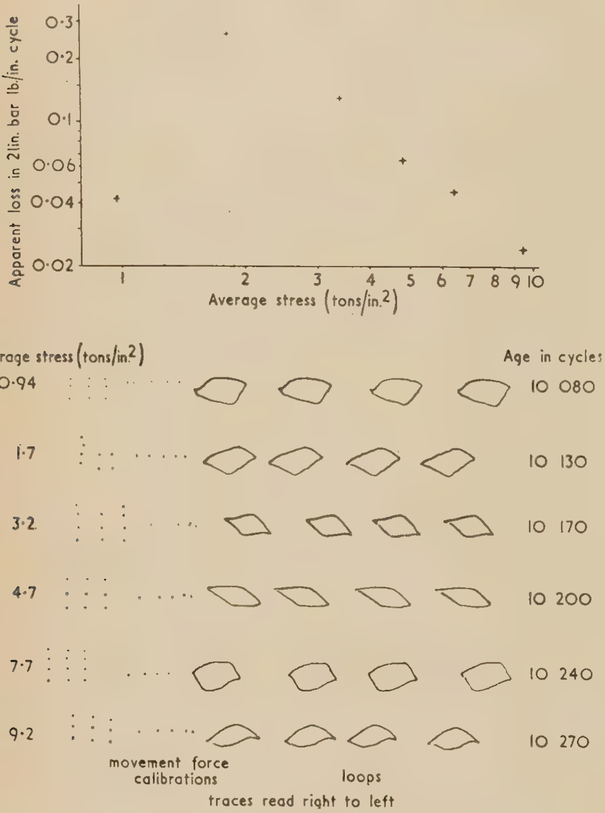

Fig. 7. Effect of direct load on steel specimen

Material: 0·500 ± 0·003 in. diameter 21 in. gauge bar. Constant amplitude: 1·55 tons/in^2, 20·0 s/load cycle. In traces: force is horizontal, movement of specimen is vertical.

Correction to the observed loop. It is believed, in view the agreement of the loss figure with previous results, that th ring loss is small. Further work on this matter is to undertaken.

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The writer is indebted to Professor D. C. Johnson, Leeds for discussion. The ring was given by the United Steel Co Sheffield.

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APPENDIX

Work function of the apparatus. When the output voltag from the bridge is amplified and rectified the voltage e' obtained which represents non-linearity of the specimen as function of load, with the spring as linear reference membe Suppose that the "spring" is not in fact linear but would, put in place of the specimen, give a rectified voltage f' whe compared against a truly linear spring. The screen of th cathode-ray tube is shown in Fig. 8, with force and moveme scales marked on it. Work represented by loop, over elemen δP, is $\delta P(e_1' - e')$. But e' is only the movement relative t movement of the ring. The true specimen movement i $(e' + f')$.

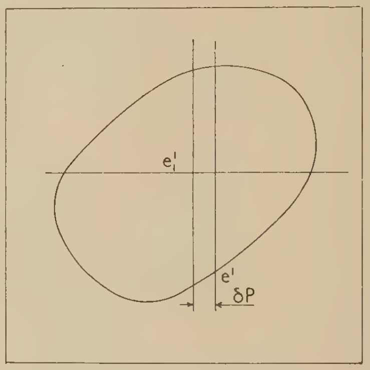


Fig. 8. Energy diagram

Work done on specimen over element δP of forc $= \delta P[(e' + f')]$.

Work over cycle $= \int (e' + f') \, . \, dP$.

No stipulations have been made here about accuracy adjustments, either mechanical or electrical. The work ove the cycle is given by the equation independent of adjustment The effect of these is only to make the loop easily observable

Spherical aberration in the Fizeau interferometer

By W. G. A. Taylor, National Physical Laboratory, Teddington, Middlesex

[*Paper first received* 6 *February, and in final form* 29 *March*, 1957]

The drawbacks of types of instrument in common use are reviewed. It is shown that primary aberration theory predicts quite accurately the errors introduced even by simple collimators with large aberration. The advantages of using a collimating lens based on a multiple-meniscus design are indicated, and the performances of several lens-systems are compared.

e Fizeau interferometer,(1) in its application to the measure- nt of the flatness of surfaces, is commonly called an inter- oscope. The choice of name is unfortunate; it may suggest t the instrument cannot be used for quantitative work, d this is not necessarily true. A number of factors limit accuracy of measurement. Of these, one, the effect of ng a source of finite size, has been considered by Bruce(2) d Thornton.(3) This paper assumes a point source, and nsiders errors due to imperfect collimation; in particular, se due to residual aberration in the collimator itself.

THE INTERFEROMETER

In the measurement of flatness with the Fizeau system a ster surface and a test surface intercept a nominally plane vefront emerging from a collimating lens. The instrument essentially auto-collimating, and in practice it is necessary displace the eyepoint, which would otherwise be incon- niently near the source. Two methods are in common use. one the source is set slightly off the axis, and the eyepoint correspondingly displaced. In the other the source is set or near the axis of the collimator, and a plane-parallel flector inclined at a convenient angle to the axis (generally out 45°) is placed between the source and the collimator; reflected wavefronts, before converging to the eyepoint, intercepted by the reflector.

The retardation ρ due to the air gap is given by

$$\rho = \frac{2t \cos i}{\lambda}$$

ere t is the perpendicular distance between the master and t surfaces, i the angle of incidence on the test surface and the wavelength of the incident light. To the degree of proximation required here, the change in retardation rresponding to a change from normal incidence to angle of cidence i is $\frac{ti^2}{\lambda}$. It is clear that even if the collimator is errationless the fringe patterns obtained with the two ethods will not agree. In the first system the value of i ll be constant across the wavefront and the correction for liquity of incidence is simple. In the second system the vefront emerging from the collimator will be affected by y spherical aberration, coma and astigmatism introduced the reflector; the value of i will vary across the wavefront. ny(4) has shown that the coma and astigmatism can be gely removed if the reflector, instead of being plane- rallel, has its faces inclined at a very small angle. The sidual over-corrected aberration, for plates of the thick- sses generally used, will cause little trouble; even if not gligible it will serve to offset the under-corrected aberration the collimators generally employed.

When the collimator has residual aberration a simple liquity correction cannot be applied.

The master flat, interposed between the collimator and the st surface, will itself affect the shape of the wavefront incident on the latter. Its effect will depend on the angle between its faces, the residual aberrations in the remainder of the system and the obliquity of incidence. Sufficient has been said to indicate that where results of high accuracy are required the two forms of the instrument cannot be regarded as interchangeable.

In general, the better the collimator the better the performance of the instrument, and the following discussion is devoted mainly to the effect of residual aberration in the collimator. For simplicity it is assumed that a point source lies on the axis of the collimator, that the surfaces to be compared are truly plane and parallel and that for the axial normal to the emergent wavefront i is zero. The angle i, between the normal at any point on the emergent wavefront and a line through that point parallel to the axis, is then called the angular aberration of the wavefront at that point. The quantity $\frac{ti^2}{\lambda}$ is the error, measured in fringes, due to angular aberration i.

ANGULAR ABERRATION AND POSITION OF FOCUS

The primary angular spherical aberration of a collimator is proportional to the cube of the aperture. A shift of focus p introduces a term directly proportional to the aperture. The angular aberration of the emergent normal for a zone of fractional aperture r_z is

$$i_z = \frac{p \sin U_m r_z}{f} + a_m r_z^3$$

where f is the focal length, U_m the maximum angular semi-aperture and a_m the primary angular aberration of the marginal zone. The angular aberration is considered positive when the emergent normal diverges from the axis; the cubic term is then always negative and p is positive when the source lies inside the paraxial focus.

If l_m is the marginal longitudinal aberration

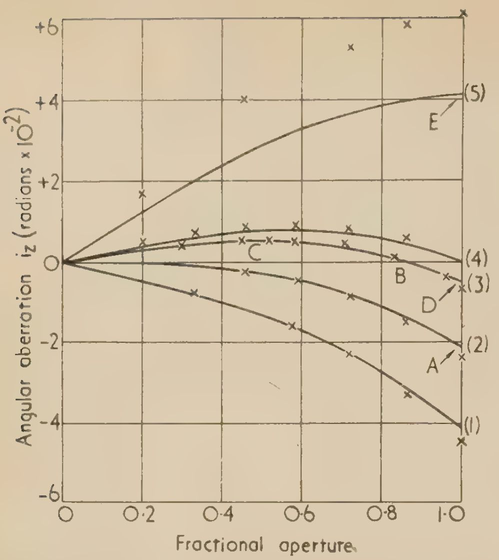
$$a_m = -\frac{l_m \sin U_m}{f}$$

and, since

$$r_z = \frac{\sin U_z}{\sin U_m}$$

$$i_z = \frac{1}{f}\left(p \sin U_z - \frac{l_m \sin^3 U_z}{\sin^2 U_m}\right) \qquad (1)$$

The full lines in the figure show the variation of i_z with fractional aperture and position of source, on the assumption that the aberration is entirely primary. The example chosen is the plano-convex lens described in the table. The crosses in the figure are the results of ray traces, and the fact that the two sets of results agree so well for a lens with large aberration ($l_m = 3$ cm, $f = 38$ cm) shows that the primary theory gives



Variation of angular aberration with position of focus. Source (1) outside paraxial focus, p negative; (2) at paraxial focus, $p = 0$; (3) at position of best focus, $p = \frac{3}{4}l_m$; (4) at marginal focus, $p = l_m$; (5) inside marginal focus (maximum at margin), $p = 3l_m$

reasonable accuracy even for systems of high relative apertur The more complex systems in the table give much close agreement.

From equation (1)

$$(\sin U_z)_{\max} = \sin U_m \left(\frac{p}{3l_m}\right)^{\frac{1}{2}}$$ (2

whence

$$(i_z)_{\max} = \frac{1}{f} \cdot \frac{2 \sin U_m}{3^{\frac{3}{2}}} \cdot \frac{p^{\frac{3}{2}}}{l_m^{\frac{1}{2}}}$$ (3

The maximum of curve (4) (source at marginal focu occurs at fractional aperture $\frac{1}{\sqrt{3}}$ and is numerically equal t $\frac{2}{3\sqrt{3}}$ of the greatest value obtained with the source at th paraxial focus [curve (2), point A].

Between the paraxial and marginal foci there will be position of the source at which the negative marginal aberra tion is numerically equal to the maximum zonal aberratio For this position of the source the maximum error due t angular aberration of the wavefront will be less than for a other position. The condition that the source should be a this position of best focus is

$$l_m - p = \frac{2}{3^{\frac{3}{2}}} \frac{p^{\frac{3}{2}}}{l_m^{\frac{1}{2}}}$$

Table. *Comparative performance of interferometer collimators*

System	*Radii of curvature (cm)*	*Diameter (cm)*	*Axial thickness of components (cm)*	*Focal length (cm)*	*Back focal distance (cm)*	*Maximum error for position of best focus (10^{-3} fringe)*	*Maximum erro for displacemen 0·1 cm from po tion of best fo (10^{-3} fringe)*
4-Component	+ 80·04 −1077 + 45·24 − 101·6 + 31·50 − 50·62 + 24·23 − 35·76	20·3	1·3	38·6	35·7	0·002	4·2 4·2
3-Component	+ 66·65 ∞ + 37·69 − 98·30 + 26·24 − 45·24	20·3	2·0	40·1	36·6	0·4	3·7 6·6
2-Component	+ 45·36 + 307·8 + 24·49 − 64·34	20·3	2·0	37·8	35·3	8·6	16·6 26·0
Single lens (form for minimum spherical aberration)	+ 22·73 + 155·4	20·3	3·0	(Paraxial) 38·4	(Paraxial) 36·6	290	300 340
Plano-convex	+ 20·32 ∞	20·3	3·2	(Paraxial) 39·1	(Paraxial) 36·8	340	350 410

3y the substitution $p = l_m r_z^2$ this becomes a cubic in r_z, only admissible value of r_z being $\frac{\sqrt{3}}{2}$. The position of t focus accordingly divides the distance between the axial and marginal foci in the ratio 3 : 1 and is at the us of a zone whose fractional aperture is $\frac{\sqrt{3}}{2}$ [curve (3), nt B]. This position corresponds with the centre of the st circle of confusion determined geometrically. The gular aberration at points C and D is only one quarter of t at A. If $p < \frac{3}{4}l_m$, the numerical maximum of the angular erration always occurs at the margin. This is also true if $\geqslant 3l_m$. Curve (5) is drawn for the case $p = 3l_m$. Accord- to the primary theory the aberration at point E is twice t for point A. When it is remembered that $3l_m$ is in this e 9 cm and f only 38 cm the discrepancy between the ults obtained from the primary theory and those obtained ray-tracing is scarcely surprising.

The error in the observed fringe system varies with i^2. e foregoing results show that the maximum error with the irce at the paraxial focus is sixteen times that with the irce at the position of best focus and about seven times t with the source at the marginal focus. The importance correct focusing is clear.

t is of interest to determine, for the lens systems discussed er in the paper, the effect of a small displacement on either e of the position of best focus. The table shows, for certain ined conditions, the maximum error to be expected when source is at the position of best focus and the maximum or when the source is displaced axially 0·1 cm on either e of this position.

f the full aperture of the collimator is not being used, then attain the highest possible accuracy the source must be iced at the position of best focus for the effective aperture. e maximum error varies roughly with the sixth power of aperture employed.

CHOICE OF COLLIMATOR

There was a demand at the National Physical Laboratory systems of 35 to 40 cm focal length, to view surfaces of to 20 cm diameter as a whole. Measurements were often be quoted to an accuracy of 1/20 fringe, and for some rposes greater accuracy than this was desirable. The last lumn in the table shows that with the simple lenses often ed in Fizeau interferometers the attainment of such accuracy, en with the source at the best position of focus, was possible at the relative apertures considered. Also, with ises containing so much residual aberration, the difficulty focusing would tend to decrease the accuracy of measure- ent still more.

The problem was simplified by the fact that the lenses were be used with monochromatic light, and a solution was ind in the multiple lens-systems suggested by von Rohr d others, and investigated more fully by T. Smith.(5) ese systems generally consist of a number of components equal power in nominal axial contact, with a constant ference in curvature between the corresponding surfaces of nsecutive components. The systems of T. Smith were eferred; because of their greater freedom from coma ey were better adapted for use with the source slightly axis.

The number of components needed for the simultaneous mination of spherical aberration and coma from collimators of this type depends on the index of the chosen glass. A four-component collimator should, according to primary aberration theory, have an index of 1·543, and a three-component collimator one of 1·810. The former was less expensive and easier to make. Calculation showed, however, that in a four-component system of the required dimensions both aberrations could be very satisfactorily corrected for an index of 1·52.

All the systems investigated were of 38 to 40 cm focal length. Systems with higher indices have been investigated on paper, but those so far made have been of hard crown glass ($n_e = 1{\cdot}521$ approximately). The first made was a four-meniscus system of 15 cm diameter, with components of axial thickness 1·3 cm. Interferometric examination of this system showed practically no residual spherical aberration, and calculation showed that the performance should not be affected if the diameter was increased to 20 cm. This standard of performance suggested that very accurate work might be possible with a three-component hard-crown system, in spite of its inevitable slight undercorrection. The system finally chosen was of 20 cm diameter, with three components of axial thickness 2·0 cm. This thickness is thought suitable in relation to the diameter of the components being worked; but it can be varied appreciably, say by 0·2 cm, without measurable effect.

COMPARISON OF PERFORMANCE

Some investigation has been made of two-component systems; these are well worth attention, since they give results of a higher order of accuracy than that attainable with the single lenses often used. Data for a two-component system and for single lenses, as well as for the systems made, are given in the table. In comparing performances it has been assumed that the full aperture of 20 cm is employed and that the axis of the system is normal to two plane-parallel surfaces separated by an air-gap of 0·5 cm. The last two columns show the maximum value of $\frac{ti^2}{\lambda_e}$ (that is, the maximum error in fringes with mercury e line radiation as the illuminant) for three positions of focus. In the last column the upper figure of each pair corresponds to a displacement towards the marginal focus.

Computation for the systems tabulated was generally based on refractive index 1·521, the e line index for Chance Brothers' Hard Crown 519604. Additional calculations for the three-component system showed that throughout the visible spectrum the maximum angular aberration, provided the system was correctly focused for the radiation used, was so nearly constant that the maximum error could be said to vary inversely with the wavelength.

The results show that the four-component system is unnecessarily complex even for work of the highest accuracy required in practice: the three-component system, even if not precisely focused, will be capable of measurements to the accuracy of 1/20 fringe or less. The two-component system might be used for measurements of this accuracy, but the position of best focus would have to be more carefully located. To attain the same accuracy as that given by the two-component system at a relative aperture of $f/1{\cdot}9$, the single lenses must be used at a relative aperture of about $f/3{\cdot}5$.

For all systems the last surface tabulated is the surface nearest the source. A negative sign indicates a concave surface.

ACKNOWLEDGEMENTS

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A simple pulse spectrograph

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The usual saw-tooth time-base of an oscilloscope is replaced by one in which the spot moves with acceleration. Pulses from a radiation detector are displayed as bright dots which occur mainly on the side of the screen where the spot is moving slowly. Integration by time exposure with stationary film gives a record in which a constant-density line is a graph of pulse frequency against pulse height. Visual observation of the spectrum is possible with abundant pulses. The two simple circuits used employ only four tubes between them.

Various methods have been adopted for deriving a pulse spectrum from the displacement of an oscilloscope spot by incoming pulses. In one, employed by Curran in many published investigations,$^{(1)}$ the time-base is not used but the spot movements (in the y-direction) are recorded on film moved in the x-direction; the pulse distribution is then found by projection of the film on to a screen divided into appropriate channels. Hunt and others$^{(2)}$ brightened the tops of the pulses so that the film showed an array of dots, photoelectric scanning giving the pulse spectrum. This method was fully automatic but involved elaborate circuitry.

Two methods have been described for photographing the spectrum directly from the oscilloscope screen on stationary film, giving a record similar to optical absorption wedge-spectrograms. The pulse, on arrival, triggers the time-base, is stretched and is displayed as a horizontal line displaced from the time-base by a distance proportional to the pulse height. If the screen is photographed through an optical "wedge," the density of which varies in the x-direction, exposures of a few minutes give the spectrum,$^{(3)}$ preferably by high-contrast photography. Muzdeka$^{(4)}$ has described another method in which a triggered exponential time-base gives the same final effect as the optical wedge.

DESCRIPTION OF INSTRUMENT

In the present method each pulse appears as a dot on th oscilloscope screen. The time-base is non-linear but is n triggered. Provided that the occurrence of the pulses random in time, the dots will occur most frequently at side of the screen where the x-velocity of the spot is sm Time exposures (usually a few minutes) give records sim to those of Bernstein or Muzdeka. (See Fig. 3.)

The pulses are made to appear as dots by the follow method. A pulse, assumed negative, is applied to the y-pla of the oscilloscope and also to the circuit shown in Fig. (If the pulses are positive, small changes in the connexions t the second tube will be required.) Here it is differentiate and the resultant pulse amplified in the first tube, a ty 6AK5, before being applied to the second tube, a type 6J In the quiescent state the right-hand half of the second a the left-hand half of the third tube are conducting, the othe halves being cut off.

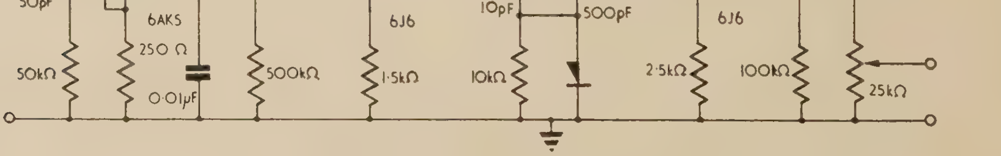

Fig. 1. Pulse-brightening circuit

The arrival of the differentiated pulse from the first tub raises the potential of the grid of the second tube (left) an this half begins to conduct. The plate of the second tub (left) falls and with it the grid of the same tube (right) whic ceases conducting until the central 10 pF capacitor discharge ough the $0\cdot5$ MΩ variable resistor, whereupon the tube erts suddenly to its quiescent state.

he flat-topped pulse resulting from the switching on and of the second tube (right) is now differentiated, giving two v pulses, one positive, the other negative. The positive is rejected through the rectifier between the second and d tubes and the negative one initiates a similar temporary nge in the condition of the third tube. In the quiescent e the left-hand side of this tube conducts, the right is off.

lence a positive pulse is applied to the *z*-axis of the illoscope for an interval dependent upon the setting of the IΩ potentiometer. Thus the spot is made brighter at an itrary short time after the sharp rise of the pulse and is t bright for another arbitrary interval.

he settings of the two potentiometers are made sub- ively until the pulses give the sharpest possible dots on screen. This is facilitated by temporarily using a high ep frequency; the pulses now appear as short arcs which adjusted until they approximate to short horizontal lines he pulse maxima.

f all pulses are to appear as small dots it is desirable that y should all be of the same shape. If there is a large range ise times some of the pulses will appear as vertical smears ead of dots, resulting in loss of resolution in the pulse- ght spectrum. Should this loss be serious it will be essary to resort to pulse-stretching. This, of course, ans complicating the instrument and also reducing the at which pulses may be accepted.

esolution is also impaired by lack of "squareness" in the ghtening pulse from Fig. 1. Stray capacitance in the le connecting this circuit to the oscilloscope was found to e adverse effects. In addition, the oscilloscope used ımont type 208B), not being designed for high-frequency rk, exhibited undesirable capacitance to earth in the fly- k suppressor cable. This cable was superfluous in the sent application and was disconnected.

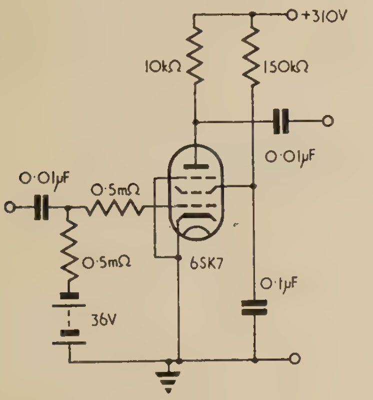

Fig. 2. Time-base circuit

The non-linear time-base may be produced in various ways. proximately exponential variation of voltage with time is en by the ordinary thyratron time-base circuit, the capacitor ng allowed to charge more fully than usually, thus giving rked departure from linearity. This method permits asurement of only a limited range of spectrum line ensities, for reasons discussed later.

This range may be greatly extended by use of an alternative thod. In this the saw-tooth voltage which provides the illoscope with its normal time-base is tapped off and plied (Fig. 2) to the grid of a heavily biased remote-cut-off tube. The plate voltage of this tube is then applied to the *x*-plates of the oscilloscope and yields a time-base permitting line intensities having a ratio of some hundreds to be measured.

THEORY OF TIME-BASE

The following considerations give some guidance in selecting a wave-form for the time-base voltage. If the oscilloscope spot moves in such a way that the displacement x is related to time by the equation

$$t = f(x) \tag{1}$$

then, to move a distance Δx the spot requires time $f'(x)\Delta x$. If dots due to pulses of a given height are being produced at the rate of N per second, the number of dots ΔN occurring in the interval Δx is $Nf'(x)\Delta x$. That is, the linear density of dots at the height concerned is $Nf'(x)$. The spectrum is a constant density locus, so, for points on this locus,

$$N \propto 1/[f'(x)] \tag{2}$$

If, as mentioned above, an exponential wave-form is used,

$$x = a\,\mathrm{e}^{-bt} \tag{3}$$

Then, since

$$t = (1/b)\log_e (x/a) = f(x) \tag{4}$$

Therefore

$$f'(x) = -1/bx \tag{5}$$

and

$$N \propto x \tag{6}$$

Hence the height of a peak in the spectrum is proportional to the intensity of the line. This restricts the range of intensities that may be measured.

If

$$x = a \log_e bt \tag{7}$$

we find

$$x \propto \log_e N \tag{8}$$

A time-base operating according to this law therefore permits a large range of intensities to be measured and also has the advantage that ratios of spectrum line intensities are measured as differences and the zero for x-measurements does not need to be known.

USE OF INSTRUMENT

The black-white transition marking the spectrum profile, or, more generally, a line of constant photographic density, is a locus of points where the number of dots per unit area on the film is constant. Since the dots are assumed random in time this number is statistically variable, the variance being the number itself. Hence if the dot density is large the spectrum profile is more reliable. For maximum accuracy, therefore, two procedures present themselves. One is to increase the exposure time, the other to work with a constant density line as near as possible to the "slow" end of the time-base. In either case it may be found desirable to decrease the blackness of the film, which may be done by stopping down the camera, using slower film or different development or by reducing the spot brightness with the final potentiometer in Fig. 1.

Slight defocusing, if it can be tolerated, also gives statistical smoothing out. Rather more useful is astigmatic defocusing by means of a cylindrical lens (say three dioptres) in front of the camera lens. According to its orientation this lens permits better measurement of spectrum "line" position at the expense of line intensity, or *vice versa*.

The method retains some of the limitations of grey-wedge and other oscilloscope methods. These include non-linearity due to curvature of screen, hum and noise effects and channel broadening due to imperfect focusing. Methods of dealing with these are discussed by Bernstein.$^{(3)}$ Some of the difficulties of the grey-wedge method, including failure of reciprocity law and intermittency effect, do not arise here. Calibration of both pulse height and pulse frequency scales is empirical.

Fig. 3 is a spectrum of the radiation from ^{65}Zn, observed with a commercial scintillometer. The small peak on the left is the time-base, broadened somewhat by hum and exhibiting a tail in the negative energy direction because the cathode-ray spot slightly overshoots the time-base on completion of pulses. Two prominent peaks (0·20 and 1·14 MeV) and various minor peaks are discernible. By reflexion photometry on a print it has been found possible to fix the ordinate of a constant density line to an accuracy of about 3%. In the present case the source was of the order of 1 μc located about 5 cm from the crystal. The exposure time was five minutes at $f/2{\cdot}8$ on Kodak Plus X film. The more prominent spectrum lines were easily visible on the screen. With more intense sources, and particularly with long-persistence screens, the instrument may prove a useful visual spectroscope for nuclear radiations.

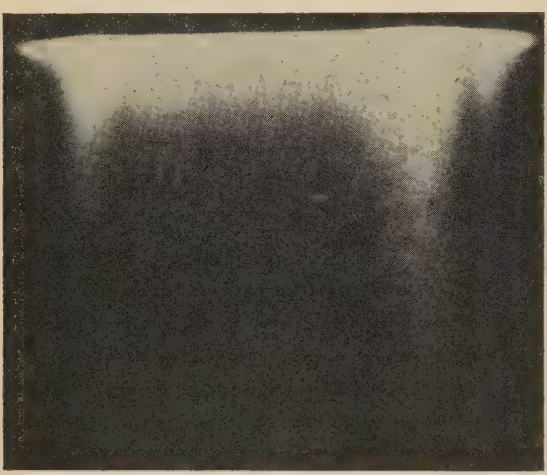

Fig. 3. Spectrum of ^{65}Zn

In Fig. 4 is displayed a spectrum produced by supplying the spectrograph with artificial pulses of constant height. These were initially of length 1·5 μs, but were rounde somewhat in amplification. Half-way through the exposur the height was changed by 1%, so that two spectrum line appear. (The time-base is at the left, broadened by halation. It appears that energy resolution of the order of 1% may b expected of the spectrograph.

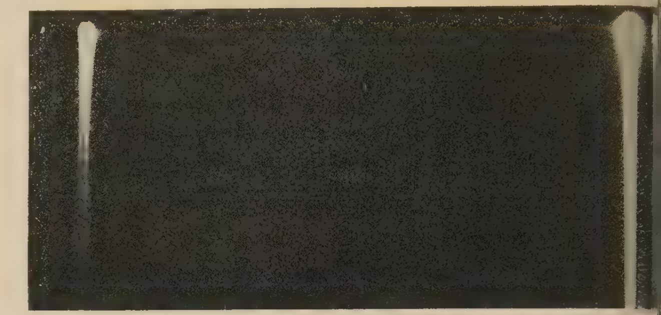

Fig. 4. Test of resolution

The author has chiefly used the instrument in the displa of X-ray fluorescence spectrograms using a proportiona counter as analyser of the soft fluorescence radiation. I this application the counter itself limits resolution to a muc greater degree than does the pulse-brightening devic described here.

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A precision capsule-type pressure gauge for the range 0–20 mm of mercury

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The construction and calibration of a capsule-type pressure gauge for the range 0–20 mm of mercury is described. Incorporating both mechanical and optical amplification of the capsule movement, the gauge is direct-reading and independent of the nature of the gas under pressure. Sources of error in construction and calibration are examined and an accuracy of better than 1% at 1 mm of mercury and 0·1% at 20 mm of mercury is shown to be obtained.

uges which may conveniently be used for precise pressure easurements in the range 0–20 mm of mercury are the oil nometer, Bourdon, capsule and capacity-type gauges. e oil manometer suffers from the disadvantages of absorp- n of the gas under pressure, drift in reading due to the nning back of the oil film which adheres to the glass walls, d large changes in the oil levels caused by thermal expansion. e capacity-type gauge is indirect-reading and sensitive to echanical vibration, while both the Bourdon and capsule- e gauges normally employ mechanical linkages prone to nsiderable backlash.

The capsule gauge described employs a beryllium–copper acuated capsule as the pressure sensitive element. The pansion and contraction of the capsule is amplified first echanically and then optically.

CONSTRUCTION OF THE GAUGE HEAD

The constructional details of the gauge head are shown in g. 1. The capsule is that used normally in the 0–20 mm of ercury gauge manufactured by Edwards High Vacuum Ltd. d is mounted by means of two retaining screws to a circular el plate. This plate is screwed to the steel casing, the lume enclosed by the plate and casing being pumped *via* e ½ in. diameter hole as shown. The brass spigot which is ft soldered to the capsule carries a precision steel ball hich bears against a hinged circular plate. The plate, made f brass and with the rear surface highly polished to allow nooth motion between it and the ball, rotates on a spindle inning freely between two jewel bearings in the brass stirrup. he position of the axis of rotation relative to the spigot ay be varied by adjustment of the screws securing the stirrup to the steel supporting plate. A concave mirror of 1·5 cm diameter and focal length 33 cm is fixed to the front surface of the plate with W. 40 high vacuum wax.

The spindle is made from watchmaker's pivot steel with the pivots burnished to a high polish. Provided the clearance between pivots and jewel holes is sufficient to allow the spindle to rotate freely the magnitude of the clearance, although kept as small as possible, is unimportant since the weight of the mirror ensures that the pivots will take up the lowest positions in the jewel holes. The mirror assembly is thus supported only at three points and backlash is thereby reduced to a minimum. The performance of the gauge proved the success of this arrangement.

The cover plate is made of ¼ in. plate glass and bears against an O ring to provide the necessary vacuum seal. To prevent interference caused by reflections from the surfaces of the cover plate, the hinged plate is made wedge-shaped so that the front surface of the plate may never become parallel to the glass surfaces.

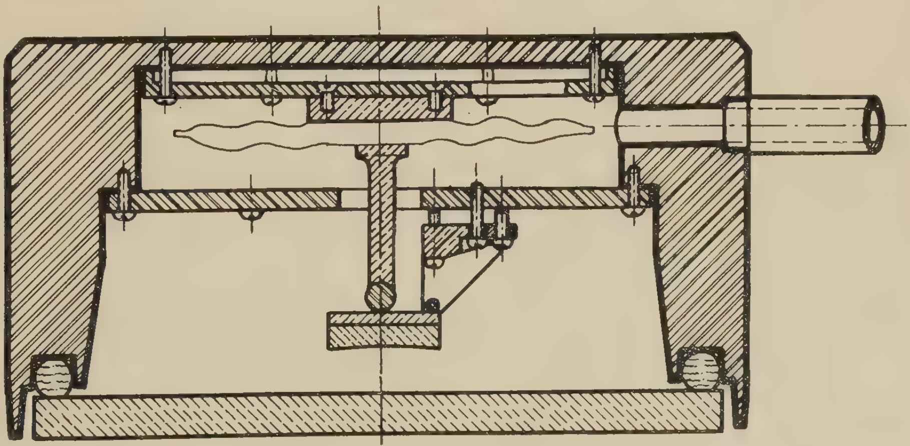

Fig. 1. Cross-section of gauge head. *Scale:* two-thirds normal size

OPTICAL SYSTEM

The layout of the gauge components is shown in Fig. 2. In order that a pressure of 20 mm of mercury should cause a deflection of the light spot over the graduated scale of 30 cm, the optical path of the reflected beam from the concave mirror was chosen as 100 cm, the length of arm between the axis of rotation of the mirror and the point of contact of the ball with the brass plate being adjusted accordingly. To keep the gauge compact in size a front aluminized plane mirror *A* was placed beside the lamp thus enabling the bar to be 60 cm in length.

The light source used is a 75 W soundfilm lamp operated from the mains supply through a 10 V transformer. The plano-convex lens which focuses the lamp filament on the concave mirror of the gauge head, has a focal length of 8 cm and is stopped down to an aperture of 4 mm in diameter in order to produce a sharply focused spot 8 mm in diameter on the scale. This stop also carries a grid of six 0·003 in. diameter Nichrome wires spaced 0·4 mm apart. The scale, 35 cm in length and graduated in millimetres, was printed on 35 mm film-strip and made translucent by roughening the reverse side with fine emery paper. The image on the scale of the graticule formed by the Nichrome wires serves as a vernier and enables an additional figure to be read. The scale is held in a curved frame with a radius of curvature of 100 cm to ensure the spot remains in focus throughout. The lower end of the scale is clamped between two metal strips which can be raised or lowered by a thumbscrew *B*, thus providing a zero adjustment.

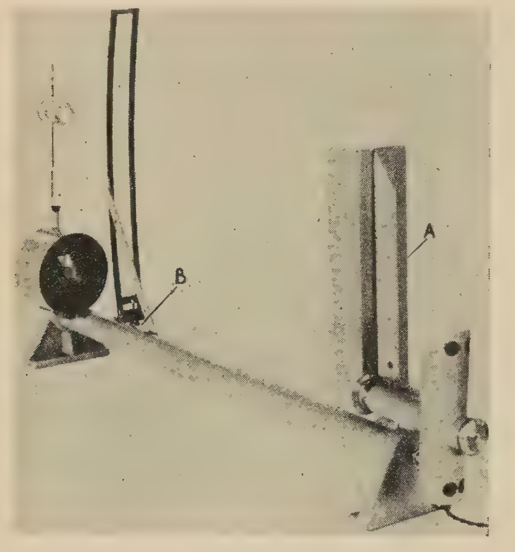

Fig. 2. General view of gauge

CALIBRATION

The only absolute pressure gauge which may be used over the whole range 0–20 mm of mercury is the mercury manometer; consequently a gauge of this type was used as the standard against which the capsule gauge was calibrated. For the particular application for which the gauge was designed it was necessary to avoid mercury contamination. The two gauges were therefore isolated by an oil manometer which also acted as a null pressure indicator.

Pressure measurements with a mercury manometer of which one arm is evacuated are subject to a number of sources of error. These are:

(*a*) capillary depression of the mercury surfaces;
(*b*) refraction due to the glass walls of the manometer;
(*c*) inability to determine accurately the position of the mercury surface;
(*d*) pressure changes in the evacuated arm.

(*a*) Cawood and Patterson(1) have measured the capillary depression of a mercury surface in tubes having a range of diameters. Capillary depression in the tubing of 28 mm bore from which the manometer was constructed is show by their results to be negligible.

(*b*) The effect of refraction was investigated by the meth used by Cawood and Patterson(1) and shown to be negligib if the arms were kept accurately vertical.

(*c*) In the present calibration the mercury surfaces we viewed with parallel light. The interference fringe syste which is then observed above each surface has been discuss by Ziesing(2) who showed that it was a "Lloyd's Mirror" ty of interference phenomenon from a curved surface. Attemp to aline the crosshairs of a reading microscope on a mercu surface are usually inaccurate due to blurring caused by th first interference fringe. In the present instance, howeve since displacements rather than absolute positions were be measured it was sufficient to aline the crosshairs on a one of the fringes of higher order, these being very sharp defined. On investigation, it was found that these fring accurately preserved their spacing relative to the mercu surface when the surface moved through the maxim excursion of 1 cm.

(*d*) It is important that the evacuated arm should rema under high vacuum throughout the calibration. A one lit flask was therefore connected to this arm in order to redu the rate of rise of pressure due to degassing, while a liq air trap was included in the vacuum line to remove co densible vapours.

When taking calibration points both gauges, separated the oil manometer, were first pumped independently to than 10^{-3} mm of mercury. The air introduced to both si was dried over liquid air, the rate of introduction being ea controlled by means of vacuum taps on two gas reservo Both sides were pumped out after each calibration point h been taken to ensure no zero drift, while all measurements the displacements of the mercury levels were repeated at le once and averaged. The calibration was carried out over period of fourteen days and no drift in calibration could detected in that period.

The major error to which the gauge is subject and whi became apparent during calibration is the hysteresis of t capsule. To investigate the magnitude of the error the gau was taken up to atmospheric pressure for one hour. Aft pumping out and resetting the zero several check points we taken. No change in calibration could be detected. Ho ever, when the gauge was under a pressure greater tha 10 mm of mercury for a number of hours a slight drift calibration was measured. When this occurred, the poi taken for calibration purposes was the final reading reach by the gauge. At 15 mm of mercury pressure the largest dri measured was 0·3%. This hysteresis drift would seem to the limiting factor to the accuracy of this type of gauge the range 10–20 mm of mercury. Throughout the fourtee day period in which the gauge was calibrated, daily ze adjustments of the scale were required. The adjustme were of the order of several mm of scale but on taking seve check points it was found that these adjustments in no w affected the calibration.

The graph of pressure versus scale reading is a smoo curve with slight curvature, the scale increment per mm mercury being 1·74 cm at 1 mm of mercury and 1·18 cm 20 mm of mercury. In plotting this curve the maximu scatter of the 58 points recorded was 0·2%. Of this numb 31 deviated from the smooth curve by less than 0·1% an this deviation was also the maximum deviation of any poi in the range 0–5 mm Hg. Since the scale can be read to th nearest 0·01 cm an accuracy of 0·6% at 1 mm of mercu and 0·04% at 20 mm of mercury would be possible teresis effects were absent. The absence of any detectable klash justifies measurements of displacement on the scale this accuracy. When account is taken of calibration ors and hysteresis effects it is considered that an accuracy better than 1% at 1 mm of mercury and 0·1% at 20 mm nercury is obtained.

ACKNOWLEDGEMENTS

he authors wish to thank Mr. J. Gascoigne for the con- iction of the gauge. They also wish to record their indebtedness to Dr. R. S. Burdon for valuable discussion and advice concerning measurements on mercury surfaces. One of us, M.T.E., wishes to acknowledge the financial assistance afforded by a Philips Research Scholarship.

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An electrical resistance analogue with a graded mesh

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Details are given for the design and construction of an electrical resistance analogue having a graded mesh. The network is economical to build and, since it consists of eight separate units, it can be assembled in a variety of ways. Thus, for any particular problem in fluid mechanics or elasticity, a suitable and efficient analogue is readily available and it has been successfully used to solve a wide range of problems in these fields.

INTRODUCTION

ctrical resistance analogues(1, 2, 3) have been used to solve ny problems, in both fluid mechanics and elasticity, since analogue provides a simple solution to the Laplace iation which mathematically represents the problem. In arge number of these cases it is desirable to have a very mesh in at least part of the field represented by the ilogue. This means that either a very large network is uired, or alternatively a graded network could be used; latter being the more economical to construct.

he initial purpose of the graded electrical resistance ilogue was to provide a potential analyser with a fine sh in that part of the field where, for example, in aero- iamic problems, the aerofoil would be represented. In lition, it was desirable to have the graded parts of the net- rk as standard items so that they could also be readily iptable for other types of problems, such as may occur in sticity and soil mechanics. Generally, this means that a ded network may be required to produce a finer mesh aration along one or more edges of a uniform network, alternatively, to provide a coarser mesh separation along or more edges of a uniform network.

he existing uniform network had a mesh separation of 4 by 1/48 and was composed of 100 Ω high tolerance istance ribbon with a 200 Ω boundary, the construction ng described elsewhere by Redshaw.(3) Consequently the ded networks were designed to be used in conjunction h this existing network, and it was decided that it would be essary to decrease the mesh separation to 1/8th of the iform network mesh size.

he resultant analogue proved to be very satisfactory in eration and has already been used to solve a wide range of oblems in fluid mechanics, elasticity and soil mechanics. ese include such examples as oscillating aerofoils in a ady airstream, and the flow of water through a permeable dia under a dam with sheet piles; both these cases are being orted elsewhere.

THE RESISTANCE GRADING

Various types of resistance grading can be devised and used, but that shown in Fig. 1(*a*) was considered to be the most suitable. The desired characteristics were that the graded network should give an accurate finite-difference representation of Laplace's equation and that it should be simple to manufacture. In particular, it should be noted that all the resistors required, in this chosen grading, are in fact either equal to one resistance value or to double this value.

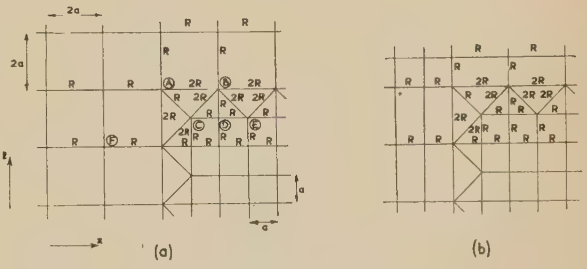

Fig. 1. The network resistance grading

(*a*) natural scale; (*b*), distorted scale.

Other gradings, for finite-difference representation, have been devised by MacNeal(4) and by Liebmann,(5) but generally speaking, the geometry and the resistance values are more complex than the corresponding properties in the network described herein. The grading given in the present paper is as accurate as any and has the advantage that it is readily adaptable to the constructional techniques developed by Redshaw.(3, 6) In the present example, to make full use of this technique, the network is not built to a true physical scale, but to a distorted scale as shown in Fig. 1(*b*).

THE MATHEMATICAL ACCURACY OF THE CHOSEN RESISTANCE GRADING

It is well known that the relationship between the electrical potentials at the nodes of a square resistance grid, of side a, with all resistances equal, and axes x and z, is

$$V_{x+a,z} + V_{x,z+a} + V_{x-a,z} + V_{x,z-a} - 4V_{x,z} = 0$$

Furthermore, the finite-difference representation of Laplace's equation,

$$\nabla^2\chi \equiv \frac{\partial^2\chi}{\partial x^2} + \frac{\partial^2\chi}{\partial z^2} = 0$$

on a similar grid is

$$\chi_{x+a,z} + \chi_{x,z+a} + \chi_{x-a,z} + \chi_{x,z-a} - 4\chi_{x,z} = 0$$

provided that terms involving fourth and higher order differentials are neglected.

These relationships show the harmonic function contained in Laplace's equation, and the electrical potential, given by a potential analyser with uniform mesh and equal resistances, to be analogous.

Similar relationships for the nodes in a non-uniform, or graded, network exist but these will not necessarily be quite as accurate as those in a uniform network. However, the accuracy of the present network is sufficient and is, in fact, as high as can be achieved with such simple gradings.

The procedure for determining the accuracy of the representation achieved by the graded network is illustrated by reference to the node B in Fig. 1(a). In this case the relationship between the electrical potentials at this node and at adjoining nodes is

$$\begin{aligned} F_B(V_{x,z}) \equiv {} & \tfrac{1}{2}(V_{x+2a,z}-V_{x,z})+(V_{x,z+2a}-V_{x,z})+\tfrac{1}{2}(V_{x-2a,z}-V_{x,z})+ \\ & +\tfrac{1}{2}(V_{x-a,z-a}-V_{x,z})+(V_{x,z-a}-V_{x,z})+\tfrac{1}{2}(V_{x+a,z-a}-V_{x,z}) \\ & = 0 \end{aligned}$$

Now if the corresponding expression in terms of the harmonic function χ is expanded by means of the expansion

$$\chi_{x+k,z+l} = \chi_{x,z} + \left(k\frac{\partial}{\partial x} + l\frac{\partial}{\partial z}\right)\chi_{x,z} + \\ + \frac{1}{2!}\left(k\frac{\partial}{\partial x} + l\frac{\partial}{\partial z}\right)^2\chi_{x,z} + \frac{1}{3!}\left(k\frac{\partial}{\partial x} + l\frac{\partial}{\partial z}\right)^3\chi_{x,z} + \ldots \text{etc.}$$

then the following equation results

$$F_B(\chi_{x,z}) = \frac{11}{4}a^2\nabla^2\chi + \varepsilon_B$$

Now since in the analogue $F_B(V_{x,z}) = 0$, then the analogy achieved at the node B is

$$\frac{11}{4}a^2\nabla^2\chi + \varepsilon_B = 0$$

or

$$\nabla^2\chi = 0$$

subject to an error ε_B.

The value of the error terms at each node of the network, up to and including the third order differentials, are given in Table 1. The coefficient of $\nabla^2\chi$ in the above equation, i.e. $11a^2/4$, has little significance since it depends upon the size of the area covered by the nodes involved in the finite-difference expression; for example, the value is a^2 for node D and $4a^2$ for node F. The values of this coefficient are also given in Table 1 for each node.

Table 1. *The error terms at the network nodes*

Node	(ε) *Error*	∇ *Co*
A	$\left[a^2\frac{\partial^2}{\partial x\partial z} + \frac{a^3}{2}\left(-\frac{\partial^3}{\partial x^3} + \frac{\partial^3}{\partial z^3} - \frac{\partial^3}{\partial x^2\partial z} + \frac{\partial^3}{\partial x\partial z^2}\right)\right]\chi_A$	$7a$
B	$\left[-\frac{a^2}{4}\left(\frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial z^2}\right) - \frac{a^3}{2}\left(\frac{\partial^3}{\partial x^2\partial z} - 2\frac{\partial^3}{\partial z^3}\right)\right]\chi_B$	$11a$
C	$\left[-\frac{a^3}{2}\left(\frac{\partial^3}{\partial x^2\partial z} - \frac{\partial^3}{\partial x\partial z^2}\right)\right]\chi_C$	$3a$
D	0	$1a$
E	$\left[+\frac{a^2}{4}\left(\frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial z^2}\right) + \frac{a^3}{2}\left(\frac{\partial^3}{\partial x^2\partial z}\right)\right]\chi_E$	$5a$
F	0	$4a$

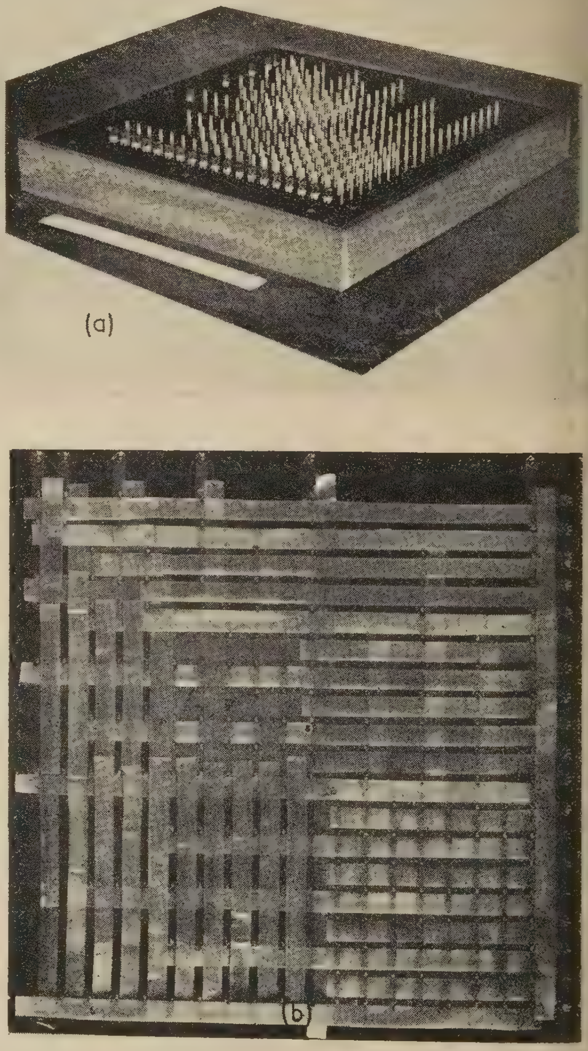

Fig. 2. A resistance board with gradings in two directions

(a) front view; (b), rear view.

In order to determine the actual value of the resistances ed in this network the problem was first solved in general ms and then the resistance values chosen so as to minimize errors.

As far as the errors are concerned, it should be noted that nodes *B* and *E*, which constitute the vast majority of des in a graded network, are self compensatory as regards second order errors.

From Table 1 it is seen that there are no first order ferential errors; hence, provided that the potential gradient approximately constant over the actual graded portion of network, high accuracy can be achieved.

THE METHOD OF CONSTRUCTION

The method of construction was basically that described Redshaw,(3) except that for graded networks the resistance bons were not placed diagonally, but were placed in both *x* and *z* directions. To avoid electrical shorting, the istance ribbons were placed between transparent insulation e before assembly.

The grading to 1/8th of the original mesh size was carried t in three stages and this meant that, by building the units the distorted scale shown in Fig. 1(*b*), only eight different es of resistance ribbon were required. Some of these bons had loops for soldering on both sides, some only on e side, and also the loop spacing varied. The resistance ween consecutive loops was 100 Ω for some ribbons and 0 Ω for the others, with a maximum tolerance of ±1%. e advantage of the distorted scale was principally that it mitted longer lengths of ribbon, with uniform resistance unit length, to be assembled in one operation than would herwise be possible. It should be remembered that the istance per unit square of a conducting sheet is indendent of the size of the square; similarly, the resistances the uniform parts of a network are independent of the size the mesh.

Photographs of a graded resistance analogue board are en in Figs. 2(*a*) and (*b*). The first figure shows the front w of the board and the second the rear view. In this e grading is carried out in both directions, the board ming a "corner" graded resistance unit.

As in the case of the uniform boards, the whole assembly encapsulated in resin on completion.

THE VARIOUS UNITS AND THE POSSIBLE ARRANGEMENTS

In all, some eight boards constituted the units for making the complete graded networks. Three of these were iform, three graded in only one direction and two graded both directions.

The particulars of these boards are given in Table 2.

The details of the gradings used are given in Fig. 3. These etches are drawn to the distorted scale to which they were nstructed. The effective scale is shown on the drawings.

The two principal methods of joining these units together shown in Fig. 4. The first method gives a fine mesh along e side of the board over a limited region. This method is y useful for aerofoil applications and gives an effective sh separation over the aerofoil of 1/424 by 1/512, over an a measuring 7 by 126 units. The second method gives a arse grading over three sides of the board so that the ective size of the main board is increased and the mesh paration therefore effectively reduced to 1/144 by 1/88, er an area measuring 55 by 78 units. This method has been ed for the study of viscous flow through a porous media.

Table 2. *The resistance boards constructed*

Board	*Type*	*Size*	*No. available*
A	Uniform	64 × 48 units	1
B	Uniform	5 × 20 units	2
C	Graded in one direction	Graded from 8 to 64 units. Effectively 5×8 units (coarse units)	1
D	Graded in one direction	Graded from 6 to 48 units. Effectively 5×6 units (coarse units)	2
E	Graded in two directions	Effectively 5 × 5 units (coarse units)	2

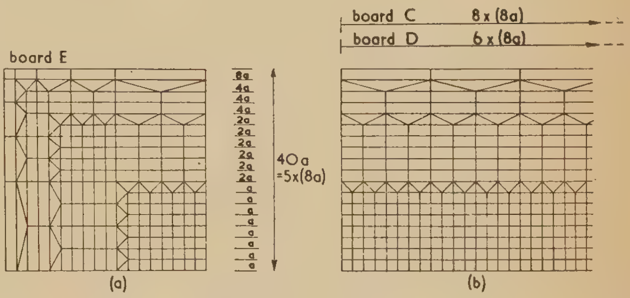

Fig. 3. Graded resistance board layouts

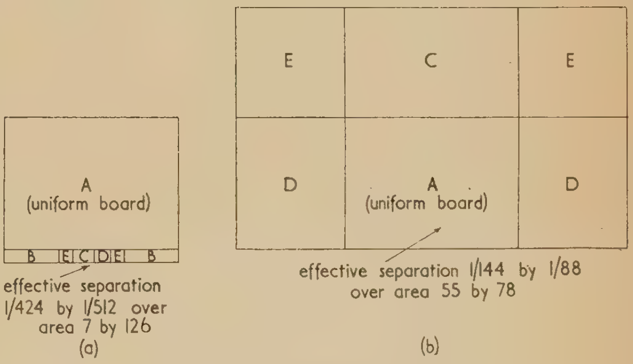
E
C
E
D
A
(uniform board)
D
A
(uniform board)
B
E
C
D
E
B
effective separation 1/424 by 1/512 over area 7 by 126
(a)
effective separation 1/144 by 1/88 over area 55 by 78
(b)

Fig. 4. Assembled networks
(Drawn to effective scale with main board size constant.)

Other methods of assembly for the various units can be devised but the two arrangements shown here serve to illustrate the technique.

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A mercury-in-glass gas burette

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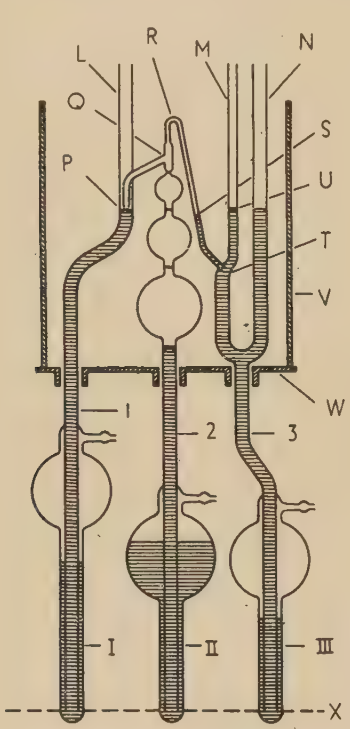
Apparatus is described for transferring increments of gas at low pressures from one section to another of a vacuum system. The measurement of the volume of the gas and the operation of transferring it involve its coming into contact with glass and mercury only.

The gas burette shown in the figure was designed for a glass vacuum system in which it was desired to eliminate the use of taps. The burette is used for introducing measured amounts of gas, at low pressures, into an adsorption bulb. The tube *L* leads to the gas reservoirs and to a pressure gauge. The tube *M* is connected to the adsorption bulb, and the tube *N* to the vacuum line. The mercury reservoirs I, II and III are supported by plaster of Paris in cylindrical stainless steel containers, through the bottoms of which the long wells of the reservoirs protrude. The Perspex enclosure whose walls *V* stand on plate *W* contains a thermometer.



Mercury-in-glass gas burette

The square-cut end *T* of the capillary tubing *QT* projects a few millimetres into column 3. The tubing *QP* is of 6 mm internal diameter, narrowing to 4 mm at *P*. The burette contains four calibrated sections, each bounded by the opening *P*, the etched mark *S* on the capillary tubing, and one of the four etched marks bounding the three bulbs in column 2. Before the top half of the burette was joined to the three mercury reservoirs, it was calibrated in the inverted position by filling each section with mercury and then emptying out and weighing the mercury. When the burette was finally assembled, the top and bottom sections of column were joined together at the middle of the *S*-bend. In carryi out the calibration, the mercury was introduced through th opening *P* by means of a funnel with a curved stem. Th mercury was brought to the level of the etched mark *S* an the etched marks in column 2 by suitably adjusting th pressure of the air in columns 3 and 2. The burette wa emptied through the tube *M* by suitably adjusting the pressu of the air over the mercury in the tube *PQ* and column 2.

Suppose that the system has been evacuated and that o now wishes to add an increment of gas to the adsorption bul The adsorption bulb is first isolated by admitting air to th mercury reservoir III and thereby raising the mercury column 3 to the level shown in the figure. The mercury column 1 is raised to just below the opening *P*. To get th required quantity of gas into the burette, the mercury column 2 is raised to one of the four etched marks, and g is introduced from the selected gas reservoir until the appro priate pressure is reached. After reading the temperatu the mercury in column 1 is raised nearly to the junction The mercury in column 3 is then lowered to just below th exit *T* of the capillary tubing.

The mercury in column 2 is now raised. When it reach the junction *Q*, some of it flows into column 1. When reaches the point *R*, which is 68 cm above the top of the we of reservoir II, the mercury starts to flow into column The surface in column 3 is raised to the etched mark U, an air is then pumped from the reservoir II. Mercury ma continue to siphon over from column 1 until the surface column 1 falls to the opening *P*, at which stage the sipho breaks up. Alternatively, it may break up in the spa below the end *Q* of the capillary tubing before the descendin surface in column 1 reaches *P*. Reservoir III may now opened to the atmosphere to return excess mercury to colum 2. The surface in column 3 is finally brought to the lev of the mark *U*. The addition of further increments of g is carried out in the same manner.

It can be seen from the foregoing description that the we of the reservoirs I, II and III must extend down low enoug to ensure that if a reservoir is opened to the atmosphere, th mercury surface in the reservoir cannot, by means of siphonin be brought down through the annular space in the well far as the level *X*. The level *X* should be 87 cm below th opening *P*. This provides a safety margin of about 10 cm.

ACKNOWLEDGEMENTS

Thanks are due to Mr. E. F. Dawes for carrying out th glass-blowing, and to the Directors of Imperial Chemi Industries of Australia and New Zealand Ltd. for permissio to publish this note.

A sensitive aerodynamic drag balance as an indicator of low air speeds

By J. F. Kemp, M.Eng., National Mechanical Engineering Research Institute, Pretoria, South Africa

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The construction and performance characteristics of a low air-speed indicator, which can be used as standard of comparison for the routine calibration of anemometers in a wind tunnel, are described. The apparatus is essentially a very sensitive drag balance in which the forces acting on a disk are utilized to determine the air speeds. The effective range is from 0·2 to 16 ft/s, and the indicator conforms to all the requirements that may be imposed on a standard of its type.

iere has been a long-felt need, particularly in ventilation ork, for a suitable instrument that will serve as a convenient d reliable standard of comparison for the calibration of emometers at speeds ranging from a fraction of 1 to about ft/s, the latter value roughly representing the lower limit which a Pitot-static tube can be used with convenience in njunction with a sensitive manometer.

Apart from the stipulated range, such a standard is required have a high inherent accuracy and a permanent calibration, iile the effect of variations in atmospheric conditions on e calibration should be compensated for, either automatically the design and operation, or else by virtue of corrections plied to the measurements. Secondary requirements that ay be imposed are ease of manipulation and quickness of sponse.

The indicator described in this paper conforms to all these quirements, and has been used successfully during the past ar for the calibration of hot-wire anemometers and vane iemometers.

OPERATING PRINCIPLES

The indicator is depicted schematically in Fig. 1; *A* represents a graduated balance arm, suspended on a horizontal rsion wire at fulcrum *C* in order to eliminate mechanical iction. Disk *B*, which is rigidly connected to arm *A*, serves "drag body" and is exposed to the airstream in the wind nnel working section.

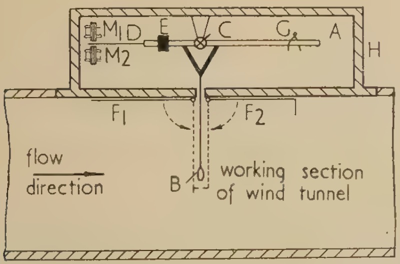

Fig. 1. Schematic sketch of the indicator

Also rigidly connected to *A* is a mild steel strip *D*, the free id of which moves in the air gap between the poles of two ectromagnets M_1 and M_2; *E* and *G* represent a counter-eight and one of a set of Nichrome riders respectively. laps F_1 and F_2 are mechanically operated, and can be vung down to enclose the disk in such a fashion that "still-r" conditions prevail at the disk and its support.

Operation of the balance is based on a null method in hich the electromagnets play a dual role. In the first istance, they form part of an electric balance-indicating stem, of the type evolved by Cox,(1) and extensively used n modern wind tunnel balances(2) in Great Britain. In this system, the electromagnets are incorporated in two arms of an a.c. bridge network, four metal rectifiers being utilized to enable balance indication by means of a d.c. galvanometer.

The bridge will be in balance for only one position (normally about central) of the mild-steel plate *D* (Fig. 1) in the air gap between the poles of the two magnets. Any vertical displacement of *D* will upset the balance, inasmuch as the inductance of one electromagnet will increase, while that of the other will decrease.

The system may also be balanced electrically to a suitable zero position by means of rheostat R_z (Fig. 2) while the variable shunt resistance R_s permits control of sensitivity at the galvanometer.

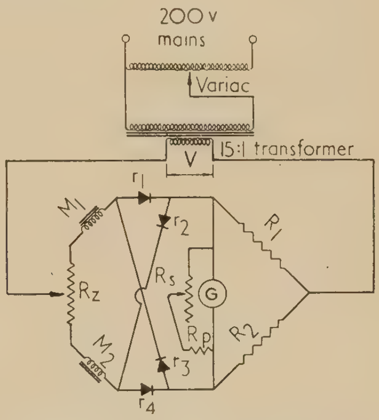

Fig. 2. Circuit diagram of balance indicator (after R. J. Cox)

M_1, M_2 = electromagnets, 3200 turns 42 s.w.g. wire on M-type yoke;
$r_1 - r_4$ = metal rectifiers (Westinghouse, Type H1, matched);
R_1, R_2 = 1000 Ω resistors, matched;
R_z = zero adjuster, 10 Ω radio-type variable resistor;
R_s = sensitivity controller, 10 Ω max.;
R_p = 10 Ω resistor;
G = spot galvanometer, sensitivity approximately 1 mm/μV.

Apart from being used as the vital components of the balance-indicating system in the manner described above, the two electromagnets fulfil a second and most useful function, in that they present a means of adjusting the sensitivity of the apparatus to any required value. For if the various moments acting on the system suspended from *C* are considered, it is clear that, under conditions of balance, any slight displacement of disk *B* parallel to the direction of flow will be opposed mainly by two negative moments. The first is due to the torsional stiffness of the wire at *C*, and the second to the weight of the suspended system, the centre of gravity of which is located below the fulcrum. The higher the rate of increase of these moments is per unit displacement of the disk, the less sensitive will the drag balance be.

Opposing these stabilizing moments, however, is a moment originated by the electromagnetic forces acting on the mild steel strip *D*. By regulating the applied voltage V to the bridge circuit in Fig. 2, this destabilizing electromagnetic moment can be set to such a value that only a small residual moment is retained for stability purposes. Comprehensive tests have also indicated that the rate of change of the combined moment is such that stability increases as disk *B* (Fig. 1) is displaced farther and farther from its position of balance. Thus maximum sensitivity is obtained at the position of balance, while it becomes practicable to operate the device under conditions verging upon the unstable. This fact, coupled with the absence of mechanical friction at the fulcrum, is the main factor that contributes to the very high sensitivity of the drag balance. Furthermore, a convenient width of air gap can be used between the poles of the electromagnets, and the torsion wire at the fulcrum can be made robust, without any loss of sensitivity.

OPERATING PROCEDURE

The indicator is calibrated in a manner described later so that the air speed, taking into account the ambient atmospheric conditions, can be determined in terms of the position of the various riders on the balance arm. When the apparatus is used for the purpose of calibrating anemometers, the following procedure is followed: The indicator is mounted on the working section of the wind tunnel, and the flaps F_1 and F_2 in Fig. 1 are lowered so that with the balance arm unloaded, balance is obtained at zero wind speed, if necessary by means of the counterweight, but normally by means of the zeroing rheostat R_z (Fig. 2). The flaps are desirable even when the tunnel fan is not running, because of the risk of natural draughts.

The relationship between air speed and rotational speed of the tunnel fan is then obtained, the latter speed being measured with high accuracy by means of a tachoscope, that is, a combined stopwatch and revolution counter. For this, the balance arm is loaded with one of the wire riders to yield each required nominal air speed, the flaps are opened, and the tunnel speed regulated until balance obtains. Speed regulation is maintained for the duration of time required to measure the fan speed with accuracy. Thus, instead o directly measuring an unknown speed by moving the rider to the required position on the arm, the arm is preloaded and the speed is controlled until balance is at hand. Hence the apparatus is named "air speed indicator" instead o "anemometer."

Having determined the relationship between nominal air speed and fan speed, the disk *B* and its support are removed the rest of the indicator being left intact on the tunnel working section. The anemometer to be calibrated is then suitabl mounted with its velocity sensing element in the position previously occupied by the disk of the indicator. A relationship between instrument indication and fan speed is once more established over the required range of air speeds Curves are plotted for both the indicator and the instrument so tested, from which the instrument indication and corresponding nominal air speeds can be derived at various value of fan speed, and the calibration curve for the instrument plotted accordingly. Corrections for ambient atmospheri conditions are described later.

DETAILED MECHANICAL DESIGN

The general arrangement of the various components ar best studied from the photograph of the indicator in Fig. 3 A substantial mild steel baseplate is provided which fit exactly on the working section of the 24 in. wind tunne The balance arm, here shown with one of the riders i position, is constructed of 2·5 mm outer diameter stainless steel tubing. The upper tube is graduated in inches and tenth of an inch, by cutting small grooves into its wall on a lathe.

The electromagnets are clamped between two fibre supports grooves being provided to enable the magnets to be move up or down if it is required to change the air gap size. Th flaps are made of 24 s.w.g. aluminium, and are actuated b means of a spring-loaded lever and a set of three pinions The spring is so arranged that the flaps are either drawn u against the baseplate as in the photograph or, in their close position pressed one against the other along their lowe edges.

The balance arm and electromagnets are housed in a air-tight Perspex box. A lid is provided to give access t

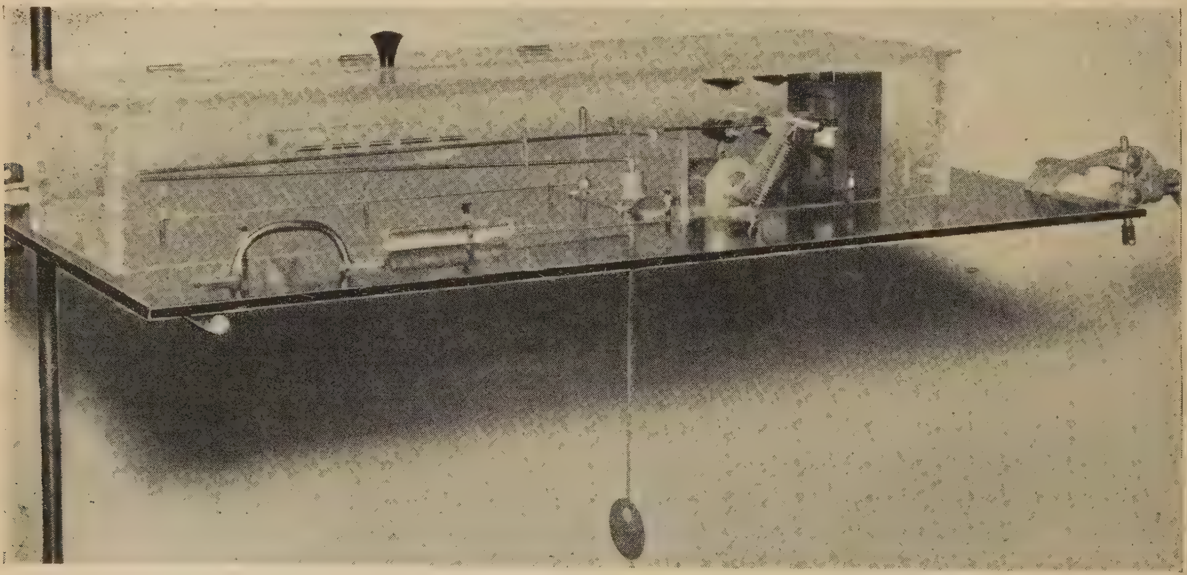

Fig. 3. Photograph of the prototype indicator

balance arm, the riders being handled by means of a ecial tool which can be seen lying on the baseplate in the otograph.

Details concerning the construction and method of susnsion of the balance arm are shown in Fig. 4. Special e was observed in the design of the suspension system to vent the torsion wire from rubbing against the sides of entry holes in the supporting pillars and in the bosses of T-shaped member which carries the balance arm. Hence se holes were made conical.

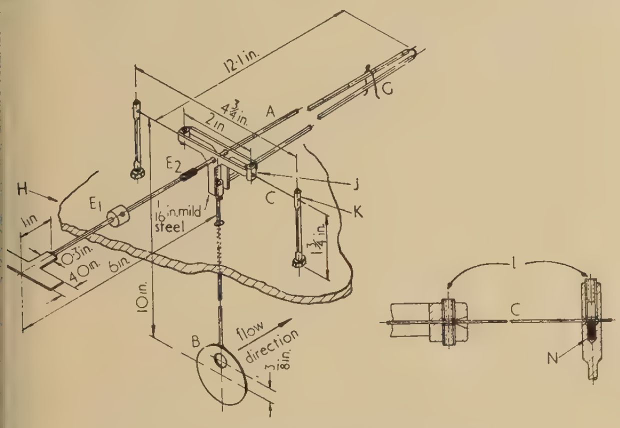

Fig. 4. Details of the balance arm

Inset.—Method of clamping torsion wire.

A, graduated balance arm, stainless steel tubes, 2·5 mm outer iameter (approx. 0·1 in.) 0·33 mm wall thickness (0·013 in.), ll joints silver soldered; *B*, $1\frac{1}{2}$ in. diameter disk with $\frac{3}{8}$ in. iameter eccentric hole. 22 s.w.g.; *C*, 24 s.w.g. stainless steel orsion wire; *D*, 24 s.w.g. mild steel strip; E_1, E_2, brass and ubber counterweights; *G*, rider; *J*, $\frac{1}{4}$ in. diameter, $\frac{1}{4}$ in. thick tainless steel; *K*, $\frac{1}{8}$ in. diameter stainless steel pillars, milled to $\frac{1}{16}$ in. thickness for flexibility; *L*, No. 6 B.A. Allen screws; *N*, steel pin (fitted).

Two counterweights, as well as the mild steel strip of the ctromagnetic balance indicator, are accommodated on the tension of the balance arm. The lighter of the two counterights consists of a short length of rubber tubing which can sily be moved on the arm and yet will have no tendency to nder along the arm under the influence of mechanical rations. The design of the disk is discussed in the following tion.

THE DISK AS DRAG BODY

The selection of a disk as the most suitable drag body was tivated by the following considerations: Being a bluff dy, the drag coefficient of a disk is high compared to that streamlined shapes, and this enhances the sensitivity of air speed indicator. Furthermore, the drag coefficient a disk becomes immune to scale effect at a comparatively w Reynolds number of flow, above which the flow pattern subject to no further change. The drag forces in this latter w region can therefore be expressed by a simple formula, th the result that the application of corrections due to riations in ambient atmospheric conditions is quite simple. nally, experimental data regarding the drag coefficient of a sk are available,(3, 4) and may be used for the approximate sign of the wire riders in such a way that a series of overpping speed ranges, covering the overall design range of e apparatus, is obtained.

Preliminary tests revealed a distinct disadvantage to using plain disk, however, in that ambiguous calibration curves were obtained in the lower range of speeds. Fig. 5 depicts two typical curves obtained for a $1\frac{1}{2}$ in. diameter sharp-edged disk, at air speeds in the range 0·35 to approximately 0·7 ft/s. Other research workers(3, 4) have, in fact, encountered severe oscillations during drag tests on disks in the corresponding range of Reynolds numbers. The fact that points invariably fell on two definite lines, with little scatter among points in each of the two groups, suggested that two fairly stable patterns existed in the flow past the disk for any given wind speed; furthermore, that ambiguity might not necessarily be attributed to fluctuations in the drag force, but rather to a wandering of the centre of pressure of this force on the disk. This surmise was proved to be correct when a $\frac{3}{8}$ in. diameter hole was drilled in the disk, at a position $\frac{3}{8}$ in. above the centre, the aim being to disturb the symmetry of flow and to induce a more stable flow pattern. In all subsequent tests a single calibration curve was obtained for each rider.

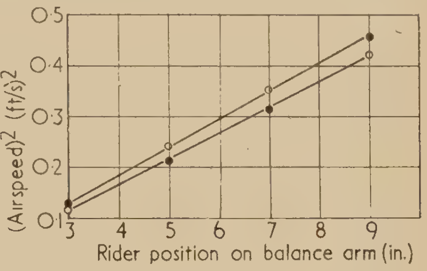

Fig. 5. Double calibration curves with solid disk

○ = first series observations. ● = second series observations.

DESIGN OF WIRE RIDERS

The weight *W* of a rider required to balance the drag force when the air velocity is v, and the air density is ρ, is given by the formula

$$W = C_d \rho v^2 A d / 2b \tag{1}$$

where d = moment arm of drag force about the fulcrum of the balance arm,
b = position of rider on the arm, measured from the fulcrum,
A = frontal area of disk, and
C_d = drag coefficient of disk, a function of Reynolds number. For the present purpose the constant value 1·17 may be used.

The speed range attainable with any particular rider can be calculated from equation (1) by substituting minimum and maximum values for b. A minimum permissible value of b was taken as 2 in., although subsequent tests proved that excellent repeatability could also be attained with riders in the 1 in. position. The maximum effective length of the balance arm was 12 in.

Thus it was possible to cover the overall design range of the indicator adequately with five riders, the weights of which were respectively 0·0034, 0·0103, 0·0474, 0·258 and 1·431 g, and these were the values actually selected. The material used for the riders was bright Nichrome wire.

CALIBRATION AND PERFORMANCE CHARACTERISTICS OF THE INDICATOR

The method of calibrating the indicator in position on the wind tunnel was essentially the same as the one subsequently adopted for routine calibrations, with the exception, of course, that the indicator was treated as the instrument under test, while a hot-wire anemometer, freshly and carefully calibrated on a whirling arm, was used as standard.

Fig. 6 depicts the set of calibration curves for the five riders, each curve having been corrected to the arbitrary "standard" conditions specified on the figure according to the theory outlined in the final section of this paper. The air-speed scale refers to the nominal speeds mentioned earlier.

As part of the experiments, readings were repeated several times with riders in the 12 and 2 in. positions, whilst similar readings were taken with riders No. 1 and No. 5 (the lightest and heaviest of the set respectively) in the 1 in. position. In this experiment, the degree to which rotational speeds of the tunnel fan repeated for each condition of loading of the balance arm could be taken as an indication of the intrinsic accuracy of the apparatus, since it was known that air speeds in the working section were virtually proportional to fan speeds, for each set of flow resistors in the tunnel.

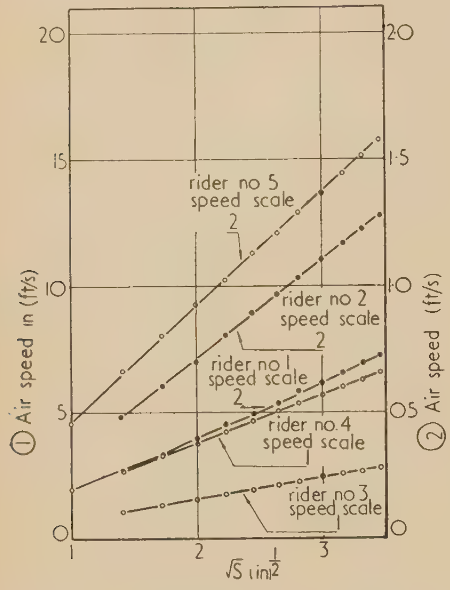

Fig. 6. Calibration curves of indicator

Air density $\rho = 0{\cdot}00200$ slug/ft^3;
air viscosity $\mu = 3{\cdot}770 \times 10^{-7}$ slug/ft s.
S = rider position on arm.

The maximum percentage variations in fan speeds were found to range from 0·2% above 5 ft/s to about 0·5% at 0·7 ft/s and 1·2% at 0·2 ft/s.

In addition to its high intrinsic accuracy, other noteworthy features of the indicator include its easy manipulation and quick response. The tunnel speed required for balancing can be set up within a matter of seconds, while the flap system enables zero adjustments or repositioning of riders on the balance arm to be performed while the tunnel is running.

It may be mentioned that the drag force acting on the $1\frac{1}{2}$ in. diameter disk when the air speed is 0·19 ft/s amounts to only $\frac{1}{3}$ mg. The fact that the relevant speed was measured with a repeatability of about 1·2% serves as an indication of the extremely high sensitivity of the apparatus in its role as drag balance.

CORRECTIONS TO SPEED MEASUREMENTS WHE AMBIENT CONDITIONS VARY

Using the indicator in a slightly modified manner the dra characteristics of the $1\frac{1}{2}$ in. diameter disk were determine The results are plotted in Fig. 7, where the ordinate f denote a function proportional to drag force and abscissa v denote air velocity. According to the results, transition to full developed flow past the disk occurs at approximately 0·7 ft/ the corresponding Reynolds number being 460. Abov this Reynolds number the force is proportional to th square of velocity, as may be expected. Below th transition point, and down to the lowest velocity at whic the air speed indicator is normally used, the force proportional to the 1·67th power of velocity.

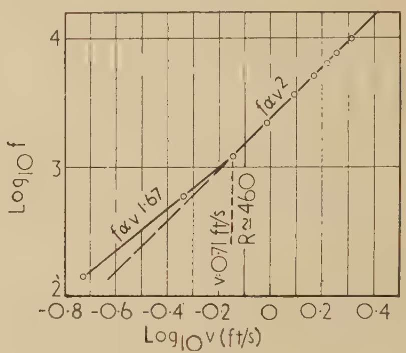

Fig. 7. Drag characteristics of $1\frac{1}{2}$ in. disk

This information can be utilized to deduce the necessar formulae for applying corrections to speed measureme when the ambient conditions vary.

In the established flow region, where the drag coefficie remains constant, we have

$$D = C_d(\tfrac{1}{2}\rho v^2)A \qquad ($$

where D, ρ and A denote respectively drag force, air densit and frontal area of the disk.

If a particular rider is placed in any specified position o the balance arm, however, D must also remain constan hence

$$v \propto \rho^{-\frac{1}{2}} \qquad ($$

Differentiation of equation (3) yields

$$\frac{dv}{v} = -\tfrac{1}{2}\frac{d\rho}{\rho} \qquad (4$$

Equation (4) may therefore be used in the region $R > 46$ in order to apply correction dv to the nominal velocity if the density changes by an amount $d\rho$ from the specifie value ρ on the calibration chart (Fig. 6).

In the lower region, ($R < 460$), the drag force D ma again be written in the usual form,

$$D = C_d(\tfrac{1}{2}\rho v^2)A \qquad ($$

where C_d the drag coefficient is now a function of Reynold number R.

According to the result obtained from Fig. 7, however,

$$D \propto v^{1{\cdot}67} \qquad ($$

Therefore, by combining equations (2) and (5) it can b shown that

$$D = k(vd/\nu)^{-0{\cdot}33}(\tfrac{1}{2}\rho v^2)A \qquad (6$$

where k is a constant, ν is the kinematic viscosity of air, and is the diameter of the disk.

or a given load on the balance arm of the indicator, that or a given drag, equation (6) can be manipulated to yield relationship

$$v \propto \rho^{-0.6}\nu^{-0.2} \qquad (7)$$

ch, upon differentiation, leads to the formula to be used applying corrections to v when $R < 460$, namely,

$$\frac{dv}{v} = -0{\cdot}4\frac{d\rho}{\rho} - 0{\cdot}2\frac{d\mu}{\mu} \qquad (8)$$

quation (8) contains the viscosity μ of air as additional able, for it must be expected that viscous forces will r into the problem in the lower flow region.

ACKNOWLEDGEMENTS

he work described in this paper formed part of a thesis mitted to the University of Stellenbosch. The paper is published by permission of the University and of the South African Council for Scientific and Industrial Research.

The author also wishes to thank Messrs. M. L. Strydom and B. van Wamelen for their assistance during the development of the indicator.

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Second-harmonic acceleration in the cyclotron

By K. E. A. Effat, Ph.D., A.Inst.P.,* and J. H. Fremlin, Ph.D., F.Inst., P., Department of Physics, University of Birmingham

[*Paper received* 1 *March*, 1957]

It is shown that steady acceleration is possible in the cyclotron, for ions which take an even number of radio-frequency cycles for one revolution, if the centre of revolution is to one side of the dee gap. The acceleration of HD$^+$ ions, taking two radio-frequency cycles to complete one revolution, has been observed and confirmed by several methods. The contribution of this process to the production and acceleration of multiply charged heavy ions is discussed.

INTRODUCTION AND THEORY

usually considered that particles can only be accelerated he cyclotron by frequencies which are either equal to, or odd multiple of, the frequency of revolution of the ticles in the magnetic field. The particles then require 1½, 2½, etc., cycles of the radio-frequency field between cessive crossings of the gap between the dees. In each , therefore, they maintain the correct phase relations for tinuous acceleration in the alternating radio-frequency l. These modes are often called fundamental, third monic, fifth harmonic, etc. In the case of even harmonics, particles will take whole numbers of cycles between cessive gap transits and therefore will alternately gain and energy without any permanent gain.

Vhile working with ^{3}He in the Birmingham cyclotron, it noticed that small beams of particles could be found ler the same conditions, capable of producing ^{13}N from arbon target, when no helium was being fed to the ion rce. Now there is no other stable ion which can have the e mass-to-charge ratio as ^{3}He^{++}, (1½), and neither is e any ion which can have an odd multiple of it.

here are, of course, stable ions which have a mass-charge o of 3, 6, 9, etc.; in particular the ions HD$^+$ and H$_3^+$, er of which might easily be found, derived from hydrogen deuterium left over from previous bombardments. Now h an ion, revolving symmetrically about the axis of the lotron, will, on the average, neither gain nor lose energy. however, it revolves asymmetrically, it is possible to gain rgy steadily. It takes two radio-frequency cycles to com- te a revolution and, if its centre of revolution is suitably one side of the dee gap, it can spend ½ cycle in transit ween gaps one side and 1½ cycles between gaps on the er side. It will then maintain the correct phase relation for acceleration just as well as an ion revolving in any of the odd harmonic modes.

Similarly, if the ion takes 4 cycles to traverse its complete orbit, it will be accelerated successfully if its centre of revolution is sufficiently displaced to give 1½ cycles one side and 2½ cycles the other; 3½ cycles and ½ cycles could also give the same effect, but the less asymmetrical arrangement will give a more nearly normal crossing of the gap and less excitation of radial oscillations, as well as shorter gap-transit time. In any of the higher harmonic modes, odd or even, the very slow-moving ions may take a considerable fraction of a cycle in a single crossing of the gap. This will very seriously impair the efficiency of fourth and fifth harmonic acceleration in any practical machine with dee gaps of normal width, and will, to all intents and purposes, prevent sixth or higher harmonic acceleration altogether.

It was considered that the ions observed here under ^{3}He conditions were likely to be the mixed molecular ions HD$_+$, which would have just twice the mass-to-charge ratio of ^{3}He, to the accuracy required. This has been confirmed in a number of ways.

EXPERIMENTS

Firstly, it was confirmed that the beam intensity rose by a large factor (800–1000) when deuterium was fed to the ion source and by a further factor of two or three when a 50% deuterium-hydrogen mixture was used. (Only a short time was available for these experiments and the ion source takes some days to clear from residual gases; furthermore, there is always a trace of water vapour and pump-oil as sources of hydrogen.)

Secondly, activation experiments confirmed the presence of deuterons; ^{13}N could have been produced by protons striking ^{13}C in the target, but it was found that an excellent yield of ^{28}Al was produced in bombardments of aluminium which can only have been by the reaction ^{27}Al (d,p) ^{28}Al.

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* Now at the University of Cairo.

A rough estimate of the deuteron energy at a radius of 48 cm was made. (A small radius had to be chosen as the magnetic field was not properly shimmed for the 10 000 gauss employed and the beam fell off very rapidly beyond 53 cm.) A stack of thin copper foils at this radius were bombarded by the particles to be identified and a separate stack was bombarded at the same radius by third-harmonically-accelerated deuterons at 4400 gauss, both with the same radio-frequency. Copper was used simply because thin (3 μ) foils were available and because the half-life of ^{28}Al was inconveniently short. The 12·8 hour isotope ^{64}Cu, produced in the reaction ^{63}Cu (d. p) ^{64}Cu, was used as a beam monitor.

In Fig. 1 is shown the variation of activity with depth in the stack for two cases. The curves are normalized to the same beam current. The mean particle energy at this radius would be 10 MeV for the fundamental mode and 1·1 MeV for the third harmonic mode. The curves suggest a mean energy of a little over 2 MeV for the particle under investigation, which is quite reasonable.

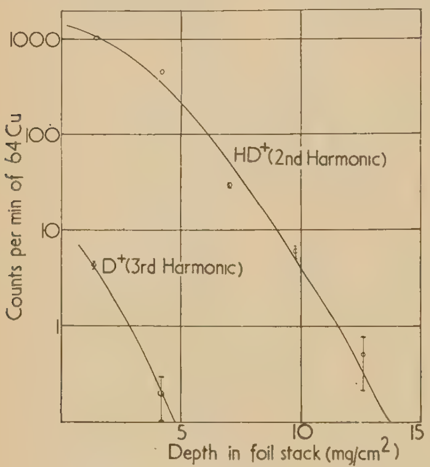


Fig. 1. Variation of ^{64}Cu activity with depth in a stack of thin copper foils bombarded with D^+ ions about 1·1 MeV mean energy and with HD^+ ions, at 48 cm radius

Thirdly, a measurement was made of the beam as a function of cyclotron-tank pressure and this is shown in Fig. 2. Over so small a pressure range no appreciable change would be expected in the current of atomic ions such as D^+, but molecular ions suffer an additional loss owing to break-up by collision with residual gas molecules.$^{(1)}$ Fig. 2 shows clearly that we are dealing with molecular ions.

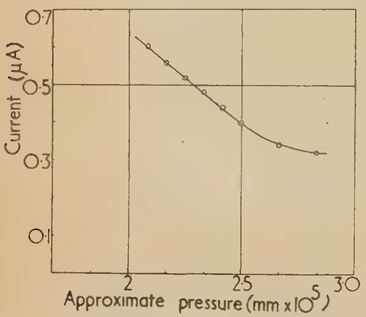


Fig. 2. Variation of beam current with cyclotron-tank pressure, at 48 cm radius

Finally, the existence of HD^+ ions of appropriate energy has been demonstrated. Owing to the incorrect shimming of the magnet, very small numbers of ions reach the exit radius, and of these probably few have their centre of revolution near enough to the axis of the system for extraction to possible. It is difficult to obtain satisfactory plates in t direct beam internally, even when the arc source current cut to a few milliamperes. Nevertheless, a few tracks ha been obtained on an Ilford C2 emulsion, as shown in Fig.

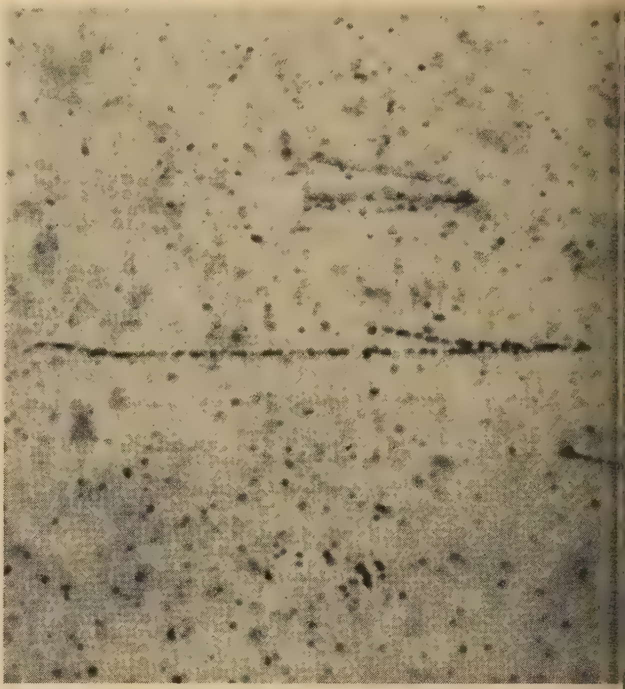


Fig. 3. Track given by HD^+ ion in Ilford C2 emulsion About 10 μ of the beginning of the track have been lost in the removal of surface blackening by slow ions

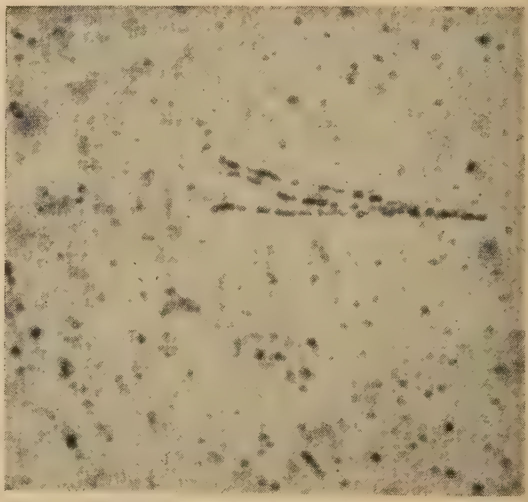


Fig. 4. Track given by H_3^+ ion in Ilford C2 emulsion

The deuteron and proton are, of course, separated by multip scattering after striking the emulsion, and give a very chara teristic asymmetrical pair of tracks. Mixed up with the HD ions are appreciable numbers of H_3^+ ions, similarly accelerate but likely to be contributing little to the activity observe If hydrogen is fed into the machine after a long period fr of deuterium, these ions may be in the majority. The trac of one is shown in Fig. 4.

DISCUSSION OF RESULTS

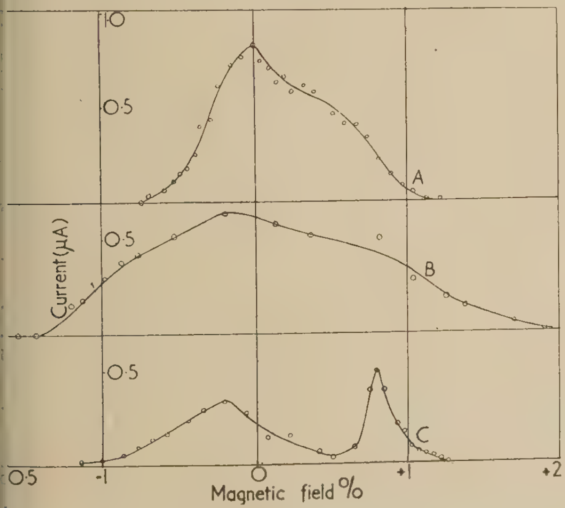
ıe importance of this second-harmonic mode of accelera- of HD$^+$ is not great, apart from its nuisance-value in work, owing to the very small currents obtained. At a cing pressure of 2 × 10^{-5} mm, and under similar arc radio-frequency-voltage conditions, the HD$^+$ current be no more than 1/300 of the D$^+$ current in the funda-tal mode. This is presumably due to the improbability apture into a suitable orbit. It may be noted too that ure into even an ideally suitable orbit does not necessarily to steady acceleration. Simple calculation shows that, he absence of precession, the centre of the orbit will ain fixed during acceleration. Hence, if initially a quarter ıe periphery of the orbit is one side of the dee gap and -quarters the other, the inequality will be steadily ced with a corresponding reduction of acceleration ency.

fact, in a real cyclotron, the magnetic field always falls owards the outside to maintain vertical focusing. Hence e centre of the orbit lies off the magnetic axis, the orbits ess in the direction of revolution of the particle. It will y be seen that in two opposite quadrants precession will to maintain the desired $\frac{1}{2}$: $1\frac{1}{2}$ ratio of the transit times r side of the gap, while in the other two quadrants ession will help to destroy it.

would, then, be reasonable to expect that the energy ibution at any target radius would show a double peak, he method used is incapable of showing very low energies the small target radius used is incapable of permitting a value for the energy of the lower peak.

ACCELERATION TIME

ouble peaks, are, however, seen in the resonance curves, h may owe their origin to this process. Information can be derived from such curves on the acceleration time. well known⁽²⁾ that, in the early stages of acceleration, became "bunched" about the optimum phase for maxi- ı energy-gain per revolution. They can thus afford to or gain phase by 90° before acceleration ceases. The tical change of magnetic field giving this phase change given radius, and for a given radio-frequency voltage, will then give a rough measure of the total number of cycles of acceleration between source and target. If the dee-gap were negligible, the magnetic field uniform, and if no loss of ions by collision or vertical oscillation occurred, clearly we should produce $\frac{1}{4}$ cycle shift in total phase after N revolutions with $100/4N\%$ change in field. Real cyclotron conditions blur this pleasant simplicity, but comparison of resonance curves for different modes is instructive.



g. 5. Resonance curves at 48 cm of curve A, H_2^+ ions ındamental resonance), curve *B*, H_2^+ ions (third- rmonic resonance)^2 and curve *C*, HD$^+$ ions (second-harmonic resonance)

In Fig. 5 the resonance curves at 48 cm with a dee-to-dee voltage of 190 kV are shown for the fundamental and third-harmonic acceleration of H_2^+ and the second-harmonic acceleration of HD$^+$. It can be seen that the peak current produced by second-harmonic acceleration is derived from a slower process than either of the others, presumably owing to a large proportion of ions being inefficiently accelerated, with only a moderate asymmetry of their orbits. Foil experiments show a slightly higher energy for the sharper peak which would fit with a longer acceleration time. The ratio of energies, however, changes considerably with cyclotron conditions and has not been investigated in detail.

IMPORTANCE OF EVEN MODES

Although this method of acceleration is not of direct practical value, it may be of significance as an intermediate stage in the acceleration of multiply-charged heavy ions. Thus when $^{12}C^{4+}$ was accelerated at Stockholm, it was expected that most ions would come from the source direct, giving a much better energy distribution than was shown by $^{12}C^{6+}$, which was known to undergo a preliminary third-harmonic acceleration in the two-charged state. This expectation was not however fully achieved, though the energy-spread of the four-charged ions was better than that of the six-charged ions.⁽³⁾ It seems extremely likely that this is due to some fourth- or second-harmonic acceleration of singly- and doubly-charged ions. For multiply-charged ions the probability of capture into eccentric orbits is much greater than for a singly-charged molecular ion as the change from the singly—to the doubly-charged state is extremely likely to take place well away from the cyclotron centre.

Direct evidence for this is difficult to obtain, but when accelerating ^{14}N in the Birmingham cyclotron a small extracted beam of ions has been observed at a deflector voltage near half that used for extracting the $^{6}N^+$, and having a range in aluminium corresponding to that to be expected for $^{3}N^+$ second-harmonically accelerated.

ACKNOWLEDGEMENTS

We would like to express our gratitude to the cyclotron team, and particularly to Mr. W. A. Hardy and Mr. F. Stewart for their patience and skill in carrying out the unusual forms of bombardment required.

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Note added in proof

Since this paper was written, together with the $^{12}C^{4+}$ beam of mean energy 90–100 MeV, Dr. Atterling has observed a slightly larger beam of low-energy particles with a peak below about 30 MeV. This peak must almost certainly represent $^{12}C^{++}$ ions accelerated by the mechanism which we have described.

Laboratory and workshop notes

A polythene tubing control valve for liquids

By A. J. H. Sale, M.A., A.Inst.P., Unilever Ltd., Food Research Department, Colworth House, Sharnbrook, Beds.

[*Note received* 23 *January*, 1957]

A simple way to control a flow of liquid is to use a solenoid to compress a section of rubber or soft plastic tubing through which the liquid flows. Some liquids (e.g. Karl Fischer reagent) attack rubber and soft plastic but do not attack polythene. However, round polythene tubing is generally too stiff for the purpose and this drawback is overcome by reshaping the tubing as follows. The polythene tubing is softened in an oven at 100° C. While the tubing is still soft, a short section is flattened between the jaws of a vice with enough pressure to reduce the wall thickness slightly, and is held in the vice until the tubing is cold. The flattened section opens slightly on releasing the pressure (see figure) and only a small force is needed to close it. A solenoid can now easily control the flow of liquid.

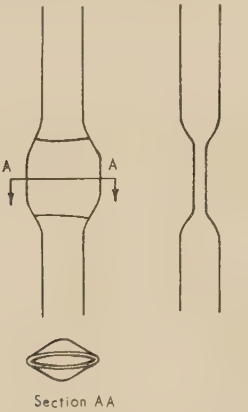

Diagram showing flattened polythene tubing

Measurement of thickness distribution of thin films by α-particle absorption

By W. H. T. Davison, M.A., A.R.I.C.,* Dunlop Research Centre, Birmingham

[*Note first received* 29 *February, and in final form* 4 *October*, 1956]

In absorption spectroscopy of polymers, it is often necessary to measure the thickness of films of 5–25 μ thickness. The thickness must be measured to the accuracy of the analysis (e.g. 1–2%) and non-uniformity can cause appreciable errors. Although weighing measured areas is possible, it is difficult with elastomers, cast films of which dry under tension. For this reason, Peterson(1) used the absorption of C^{14} β-particles to measure the thickness of films for infra-red spectroscopy. However, α-particle absorption methods are inherently more sensitive, owing to the steep slope at the end of the range, and they have been used by Shaw(2) and by Barber(3); Barber used a $\frac{1}{16}$in. diameter beam to scan for inhomogeneity. It is also possible from an analysis of the shape of α-particle absorption curve to measure the thickness/a distribution of a thin film, as well as its mean "thickness" mg/cm^2).

The apparatus (Fig. 1) used for the preliminary resu reported here consists of a thin-windowed Geiger coun (1·5 mg/cm^2) connected to a commercial scaler, and platinum foil plated with 1 μc of ^{210}Po (prepared by t Radiochemical Centre, Amersham) mounted behind aperture (10 × 3 mm corresponding to the area of beam i type DB1 spectrometer by Sir Howard Grubb, Parsons a Co. Ltd.) in an aluminium plate.

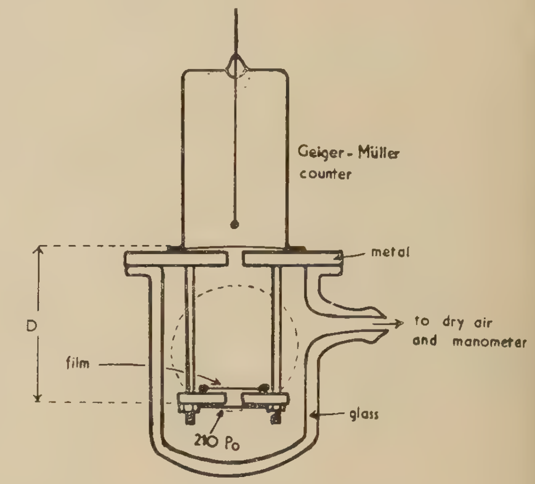

Fig. 1. Diagram of apparatus

Instead of altering the distance between the source a counter(3) the pressure of gas (dry air) between them altered, thus avoiding the inverse-square effect and obtaini a sharper slope at the end of the range. The film to measured is placed over the aperture in the aluminium pl in a corresponding position to that used in the spectromet it is introduced through a 34 mm. stoppered side tube (dot circle in Fig. 1). The corrected count-rate is measured different pressures and expressed as a ratio of the maxim count rate; plotting the relative count-rate against press gives curves of the type shown schematically in Fig. 2(*a*).

Curve 1 is with no film in the beam and shows characteristic, sharply defined range of α-particles; the ove straggling, *S*, was ⩽6% of the gas-pressure required to s the particles (see also Fig. 3).

If a perfectly uniform film, of stopping power equivalent Δp_4 of gas, were interposed the dotted curve 4 would obtained, parallel to curve 1 but displaced by Δp_4.

Interposing a real, non-uniform film (of polystyrene, example) gives a curve 5, which is no longer parallel. A point *P*, *x*% of the particles penetrate the film and an amo of gas which is Δp less than before. The stopping power *x*% of the area of the film is therefore less than that of gas equivalent to Δp. It follows that *x*% of the film is thin than *t* mg/cm^2, given by

$$t = D\Delta p\rho/760A$$

where *D* is the distance (in cm) the particles travel in the (Fig. 1), ρ the gas-density in mg/cm^3 at 760 mm of merc at the temperature of the experiment and *A* is the ratio of s stopping power of the material of the film to that of gas. If A is put equal to one, thicknesses are measured ng/cm^2 of air equivalent; this method of expressing thick- ses is used throughout this note, as the distribution of kness rather than its absolute value is being considered. ve 2 is for a uniform film with 10% of "pin-holes." If is plotted against x, thickness/area distribution curves obtained as shown in Fig. 2(*b*).

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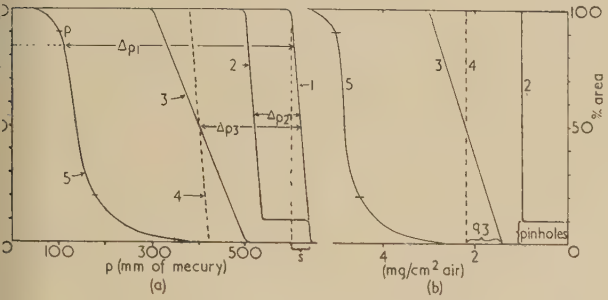
* Now at Tube Investments Research Laboratories, Hinxton Hall, Cambridge.

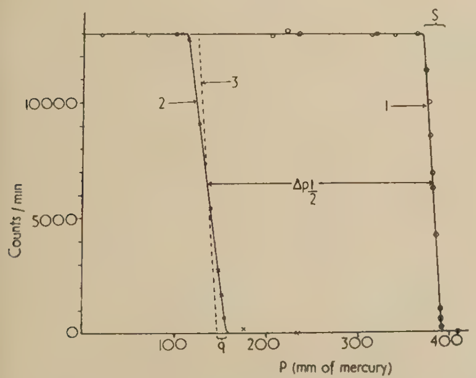


ig. 2. (*a*) Relative count-rate against pressure.) Thickness (in equivalent mg/cm^2 air)/area distribution curves derived from Fig. 2(*a*)

ırve (1), air only; Curve (2), uniform film with 10% pinholes chematic); Curve (3), wedge-type film; Curve (4), uniform m of same mean thickness as 3 (schematic); Curve (5), polystyrene film.

urve 3 is a linearly non-uniform film of the same mean kness as the uniform film shown by curve 4; q_3 is a measure ts non-uniformity. Curve 5 is typical for polystyrene, on mercury without particular precautions to ensure ormity. For this type of non-uniform film, it is necessary efine the mean thickness either as "area mean thickness" m Δp at $x = 50\%$) or "weight mean thickness" (from the under the curve in Fig. 2(*b*)). The former is readily rmined without making a complete absorption plot; for onably uniform films, it requires only two or three surements on the steep part of the curve and graphical rpolation.

ig. 3 gives experimental results for $D = 5{\cdot}5$ cm using dry at 25° C; curve 1 is for air only and curve 2 using a comcial aluminium foil of nominal thickness 10 μ. To obtain mean thickness (2·13 mg/cm^2 of air equivalent) only iires the two points at 9000 and 5400 counts/min. ve 3 is parallel to curve 1 and the deviation from uni- nity is given by q. The thickness is therefore $t_{\frac{1}{2}} =$ 3 ± 0·087 mg/cm^2 air equivalent.



ig. 3. Experimental results for commercial aluminium film (X), using dry air at 25° C(0), $D = 5{\cdot}5$ cm

Owing to the suspension of this work, the reproducibility and limitations of the technique have not been further investigated. However, some preliminary observations on the scope of the method are relevant. With ^{210}Po, which gives one of the most energetic α-particles readily available, the maximum film thickness which can be measured is about 3 mg/cm^2 but the use of thinner windows and of lower gas pressures could increase this to about 4 mg/cm^2 (around 40 μ for organic films).

It follows from the equation that errors in t are proportional to those of D and of ρ (primarily temperature variations) but are subject to a constant error from inaccuracies in the measurement of values of p. In this first apparatus, $D = 5{\cdot}5 \pm 0{\cdot}05$ cm, $T = 25 \pm 1^\circ$ C and p is ± 1 mm and the precision of mean thickness measurements is better than 2% for 25 μ and 4% for 5 μ films. The main sources of error are the pressure measurements and errors in determining D. Uncertainties of the value of D could be minimized by increasing the distance, using lower gas pressures. An alternative to the use of lower gas pressures is to use hydrogen or helium as the measuring gas. With improved apparatus, it should be possible to measure films of 5 μ thickness to 1% accuracy.

To convert the thicknesses to actual mg/cm^2 (as required for spectroscopic measurements) A must be known. This is best done by measuring weighed films of known areas of rigid polymers with the same empirical formulae as those to be measured. The mass stopping powers of carbon, nitrogen and oxygen can be regarded as equivalent within the accuracy of the method; as in the case of β-particle absorption, the H/(C, N, O) ratio$^{(4)}$ is the main factor affecting mass stopping powers.

The author thanks the Dunlop Rubber Company for permission to publish this note.

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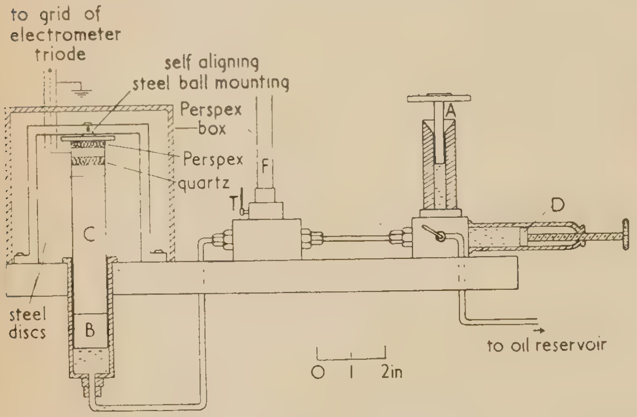
Static calibration of X-cut quartz plates used in dynamic pressure measurement

By D. H. Edwards, Ph.D., and J. C. Breeze, B.Sc., Department of Physics, University College of Wales, Aberystwyth

[*Note received* 26 *March*, 1957]

X-cut quartz plates are frequently employed in devices designed for the measurement of rapidly varying pressures. These plates require calibration before use, since imperfections which are almost invariably found in quartz plates cause the value of the relevant piezoelectric strain modulus, d_{11}, to be lower than the "best" value generally accepted. Many determinations of d_{11} by static methods are described in the literature; a brief review of the more important ones is given by Cady.$^{(1)}$ In essence the method of determining the average value of d_{11} over the crystal surface requires the sudden application or removal of a known uniform pressure to the major faces of the crystal and measurement of the resulting charge liberated. The two common methods of achieving this are the direct application of weights by means of a lever system(2) or the release of gas or liquid pressure.(3) A calibration machine, a diagram of which is shown in the figure, in which a hydraulic press is used to develop loads up to 300 lb wt/in.^{2} has been found convenient for this purpose by the authors. The loading piston *A* and test piston *B* have diameters $\frac{3}{8}$ and 1 in. respectively. On *B* rests a third piston *C*, which transmits the load to the crystal block; the lower part of the latter piston has a diameter of 1 in. whilst the diameter of its top surface can be stepped down to the diameter of the particular crystal under test. Crystals, whose surfaces are unsilvered, with diameters varying between 1 and $\frac{1}{4}$ in. have been calibrated with this apparatus. Two steel disks, with ground surfaces, serve as electrodes; one of these is insulated by a disk of Perspex whilst the other is earthed. The Perspex disk, crystal and electrodes are cemented together with a Perspex cement or Araldite 103, and the composite block thus formed is cemented to a steel block fixed to a self-aligning mounting attached to a rigid frame. The load is applied to the crystal by screwing in piston *D* and released by quickly opening a large tap *T* inserted in the pipe joining the two cylinders, which allows some oil to flow into a vertical tube *F*. When thin lubricating oil is used the pressure is released very rapidly and frictional effects in the pistons are negligibly small.



Apparatus used for the static calibration of quartz crystals

Several methods are available for recording the charge; these include the use of the Compton electrometer,(3) Lindemann electrometer, electrometer triode and tetrode,(3,4) and a cathode-follower circuit in conjunction with a c.r.o.(2) If the electrometer response is recorded visually, several seconds must be allowed for the recording, so that if leakage of charge is to be minimized, the time constant of the input circuit must be of the order of minutes. If the total input capacity is in the range 20 to 200 $\mu\mu$F, this involves resistances of the order of 10^{12} to 10^{13} Ω. An Osram ET1 electrometer triode was found suitable for this purpose when operated at an anode voltage of 4 V and the grid at −3 V. The magnitude of the voltage signal is maintained at approximately −2 V for all values of applied pressure by adjusting the value of the total shunt capacity by means of a highly-insulated variable air-capacitor. The valve is enclosed in a brass housing which can be evacuated and is partly filled with activated silica gel. A brass rod soldered into a metal bellows, which is fitted into the wall of the housing, enables the grid of the valve to be momentarily earthed, by depressing the bellows, before taking a measurement. The frame holdi the crystal block is enclosed in an air-tight Perspex box co taining silica gel. Before assembly the valve envelope, cryst and insulator surfaces are carefully cleaned with acetone a dried in a current of warm air. With these precautions gri filament resistances in excess of 10^{13} Ω are achieved. T potential developed across the grid circuit is compared wi a known potential required to produce the same change anode current.

The accuracy of the measurements of d_{11} made with th apparatus is estimated to be ±1% and close agreement observed between these and the values found by an ind pendent dynamic calibration.

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A method of storing electron microscope specimens

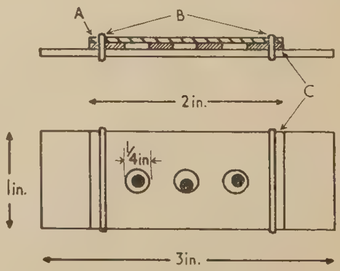
By T. B. Vaughan, M.Sc., A.I.M., Department of
Industrial Metallurgy, University of Birmingham

[*Note first received* 1 *March, and in final form* 16 *Apri*, 1957]

There appear to be few methods described in the literatu or the standard textbooks on electron microscopy relati to the storage or keeping of specimens. Drummond(1) h described a carrying case of limited capacity suitable for fi work, that fulfils certain enumerated ideal requirements f the keeping of mounted grids. The construction of such device requires much specialized machining, which renders t cost of such units prohibitive if employed for the permane storage of large numbers of replicas.

The mounted grids may be kept on pegs covered wi specimen holder caps as a temporary measure, but it uneconomic to keep equipment locked up in this way a a simple cheap method employing ordinary microscope slid has been devised.

Pieces of Perspex measuring 2 × 1 in. are cut from 1/16 sheet and a number of $\frac{1}{4}$ in. diameter holes are drilled at equ intervals along their centre lines. A large number of piec can be drilled simultaneously if clamped together. T



Electron microscope specimen file

A, top Perspex cover; *B*, elastic bands; *C*, drilled Perspex shee

ared strips are now mounted symmetrically on to glass
es, leaving ½ in. uncovered at each end to allow insertion
slide box grooves. Durofix is a suitable adhesive for
ching the Perspex to the slide. A second piece of 2 × 1 in.
spex from the same, or a thinner sheet, is used as a cover
is held in place by an elastic band near each end. The
ch shows the arrangement.

he grids holding the mounted specimen or replica are now
ed in the holes formed by the above operation; the holes
of such a diameter and depth that a grid may be easily
acted with tweezers. Alternatively, the slide may be
rted so that the wanted grid drops out. All the specimens
ne slide are exposed to contamination each time the cover is removed and there is a slight risk that clumsy handling may displace and mix the grids. It is recommended, therefore, that the number of holes per slide should be confined to three, to limit the effects of manipulative hazards. The Perspex adjacent to each hole is easily scratched to allow of identification and the device is readily kept in a standard slide box.

While not meeting all the requirements enumerated by Drummond, the present system of storage has the advantage of greater lightness, compactness, cheapness and simplicity and may be expanded in capacity indefinitely by preparing further slides.

REFERENCE

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NOTES AND NEWS

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named. When requesting copies, readers should mention this Journal.

old leaf. George M. Whiley Ltd., Victoria Road, Ruislip,
dlesex. Production guide No. 1 is the first of a series of
lications in which full information will be provided on
craft of gold beating, and its evolution into a modern
stry. It is hoped by this means to assist designers,
tsmen and technicians to select and specify the material
st suitable for each task in which they are engaged. The
number which has eight pages and is fully illustrated
es as an introduction to the subject.

lystron oscillator. Claude Lyons Ltd., 76 Oldhall Street,
rpool 3, Lancs. A leaflet describes the new "General
lio" type 1220-A klystron oscillator which generates
uencies between 2 700 and 7 400 megacycles/sec. It can
rate fixed frequencies or swept frequencies and can be
litude modulated with either square waves or pulses,
very low incidental fm.

trip chart temperature recorder. Bailey Meters and
trols Ltd., Purley Way, Croydon, Surrey. A leaflet
ribes a strip chart temperature recorder which operates
either a thermocouple or a resistance element providing
rmanent record of temperature.

acuum furnace. Edwards High Vacuum Ltd., Manor
al, Crawley, Sussex. A revised version of catalogue
77 describes a ½ lb vacuum furnace which can now incor-
ate a radiant heater assembly for sintering and brazing
general heat treatment under vacuum.

utomatic screw machine products. Anglo-Swiss Screw Co.
, Trout Road, West Drayton, Middlesex. A 12-page
trated brochure deals with the wide activities in the field
automatic screw machine products of the makers of
ision turned parts, screws and nuts.

iffraction gratings. Paton Hawksley, Rockhill Labora-
es, Keynsham, Bristol. A 7-page catalogue lists diffraction
ings formed of prismatic grooves which are claimed to
a high order of angular accuracy and virtually little or
zero reflecting or scatter surfaces. Ghost reflexions are
-existent and all gratings listed are replica gratings.

Steels and other metals. Accles and Pollock Ltd., Oldbury, Birmingham. A revised edition of a 16-page booklet has been issued to indicate the range of steels and other metals which are used in the making of precision tubes by this firm.

Organic chemicals. Chicago Apparatus Company, 1735 North Ashland Avenue, Chicago 22, Illinois, U.S.A. Catalogue 57C contains a comprehensive list of over 4000 laboratory chemicals. The catalogue also contains a complete group of the reagent inorganics, tested in accordance with the analysis shown in the catalogue. The biological stain and indicator group has been greatly expanded since the last issue and is the most current list of items now available.

Electronic, electrical, and refrigeration products. Ad. Auriema, Inc. Exporters, 89 Broad Street, New York 4, N.Y., U.S.A. The March issue of an export magazine entitled "Auri-News" gives information on new American products in the electronic, electrical, and refrigeration fields. News items and technical articles are also included.

Generator. Claude Lyons Ltd., 76 Oldhall Street, Liverpool 3, Lancs. A leaflet gives details of the "General Radio" type 1391-A pulse, sweep and time-delay generator which performs, individually and in combination, all the functions described by its title.

Electrical control station. Bailey Meters and Controls Ltd., Purley Way, Croydon, Surrey. A leaflet describes an electrical control station which provides a self-contained remote-control switch unit suitable for use with all types of electrical circuits. Two independent circuits may be controlled with one station. The unit includes an on/off switch together with an indicator lamp for each circuit.

Moisture meter. Shaw Moisture Meters, 31 Market Street, Bradford, Yorkshire. A leaflet describes a moisture meter which determines accurately the dielectric or propagation constant of a material which is directly related to the moisture content. The instrument uses very high frequency electro magnetic energy in conjunction with a new circuit, and materials such as fertilizers, detergents and chemicals can be tested.

Decade condenser boxes. Claude Lyons Ltd., 76 Oldhall Street, Liverpool 3, Lancashire. Form DC-57 describes the types 349 and KSD/1249 decade condenser boxes which can be used as components in any experimental circuits where wide-range features are desirable and where low cost is of importance.

Reflectors. Clarke, Chapman & Co. Ltd., Victoria Works, Gateshead, 8, Co. Durham. Publication No. 114B gives details of "Brytal" aluminium and silvered glass reflectors.

Radiography. North American Phillips Company, Inc., 750 South Fulton Street, Mount Vernon, New York. A new 6-page bulletin entitled: "Radiography in production control and inspection of subminiature tubes" describes techniques used by the Raytheon Manufacturing Company. Reprinted from an American technical magazine, the article deals with the basic requirements for precision radiography.

Transistorized computer. Philco Corporation, Government and Industrial Division, 4700 Wissahickon Avenue, Philadelphia, Pennsylvania, U.S.A. A 12-page illustrated brochure describes a new completely transistorized computer "Transac" type S-2000. This system, utilizing a combination of transistors, has been designed to offer the advantages of compactness, light weight, low power consumption, high speed and reliability.

Generator. Claude Lyons Ltd., 76 Oldhall Street, Liverpool 3, Lancs. A leaflet describes the "General Radio" type 1303-A two signal audio generator which can be used primarily as a test-signal source for intermodulation distortion measurements.

Galvanometric recorder. Texas Instruments Incorporated, 3609 Buffalo Speedway, Houston, Texas, U.S.A. A 6-page bulletin No. R-502 gives specifications and features of a new 2-channel rectilinear galvanometer recorder which records two functions rectilinearly on two full 4-½ in. scales on a single chart. It is available with a 10-speed fingertip-controlled transmission.

Grinding machines. Arthur Scrivener Ltd., Tyburn Road, Birmingham, 24. A 6-page illustrated catalogue gives details of a range of centreless and surface grinding machines. The manufacturers announce that any standard centreless grinding machines from their range acquired by a recognized training college will be subject to a special discount of 10 per cent.

Ionization tester. Airmec Ltd., High Wycombe, Bucks. Leaflet No. 170 describes the type 209 20 kV ionization tester which indicates the ionization threshold voltage of insulation up to 20 kV. A direct voltage, continuously variable from about 2·5 kV to over 20 kV, is available from the instrument for applying to the insulation under test.

Fuel gauge test equipment. Allied Electronics Ltd., 28 Upper Richmond Road, Putney, London, S.W.15. A leaflet gives details of the LS. 271 fuel gauge test console. This equipment contains standards of capacitance and frequency, cathode-ray oscilloscope, calibrated interpolation oscillator; 250 v. and 500 v. insulation tester and a complete set of aircraft slave equipment.

Deioniser. Elga Products Ltd., Railway Place, London, S.W.19. Details have been made available of the "Elgastat Major" deioniser which is claimed to have instantaneous action and an output of cold purified water up to 7 gallons (35 litres) per hour continuously. The deionised effluent (elgalised water) is conductivity water.

Electronic batching counter. Atkins, Robertson and White ford Ltd., Industrial Estate, Thornliebank, Glasgow. A 4 page illustrated leaflet describes the model No. 6001 electron batching counter which has been designed expressly for bot batching and summative counting. The maximum countin speed of 100 per/sec is able to deal with the operation rate o modern mechanical handling equipment and machines, an the ability to batch automatically in any number from on to one thousand covers all normal requirements.

Ionization chamber. General Radiological Ltd., 15–1 Clipstone Street, Gt. Portland Street, London, W.1. leaflet describes the type 1383A combined Beta and Gamm ionization chamber, which is a combination of a re-entra cylindrical chamber for the measurement of Gamma-ra emitting isotopes and a "parallel plate" type of chamber f measuring Beta-ray emitters.

X-ray camera. Hilger and Watts Ltd., 98 St. Pancras Wa London, N.W.1. An 8-page illustrated catalogue EN/ gives details of the Rimsky retigraph which is an X-ra camera whereby the reciprocal lattice of a diffracting cryst can be photographed without distortion. It is claimed to b simpler in principle and operation than any other camer previously designed for the same purpose.

Electric heating mantles. Isopad Ltd., Stirling Corne Barnet By-Pass, Boreham Wood, Herts. A 16-page illu trated catalogue gives details of "Isomantle" electric heati mantles for laboratory and glass plant use. New items whi have been added to the range include micro mantles for flas from 5 to 50 c.c. and multisize control units.

Magslips and synchros. Muirhead & Co. Ltd., Beckenham Kent. Publication E-1000 is a well-produced booklet whi gives full details of the Muirhead magslips and synchro A brief note on the history of remote indicating devices ope the work. Later chapters deal more fully with technic information regarding the design, operation and applicati of these devices. The booklet concludes with a comprehensi subject index.

Ultrasonic gauges. Branson Instruments Inc., 37 Brow House Road, Stamford, Connecticut, U.S.A. Bullet V-200 contains 8 pages of data on the "Vindigage" which an ultrasonic resonance instrument used for fast, no destructive testing. The instrument can be used to measu thickness of metal, glass and plastic from one side, and find corrosion, laminar discontinuities, or other flaws. Deta of various accessories are also given.

Transistor. Texas Instruments Inc. 6000 Lemmon Avenu Dallas 9, Texas, U.S.A. A leaflet describes a new grow diffused transistor designed for use as both the last IF a the audio driver stage in a reflex configuration. It has be especially designed to serve as a reflex IF in 455 kc IF rad receivers.

Power unit. General Radiological Ltd., 15–18 Clipsto Street, Gt. Portland Street, London, W.1. A leaflet describ the type 1359A E.H.T. power unit which has been design for use where a very stable source of high voltage free fro ripple and pulses is required.

Reluctance amplifier. Servo Corporation of Americ 20–20 Jericho Turnpike, New Hyde Park, New York, U.S.A Brochure RA-1 describes a reluctance amplifier which w developed primarily for driving servo motors. The unit power supply is self-contained and the manufacturers clai that it has no drift or time lags.

mall screw threads. Anglo-Swiss Screw Co. Ltd., Trout ad, West Drayton, Middlesex. A paper under the above read to the 5th International Congress of Chronometry Paris, October 1954 by P. R. Brierley, has been made ilable. The paper deals with small screw threads used in cks and watches and also with the different screw thread ems in use throughout the world, comparing one with other. The technical aspects of thread form, and of the h and diameter relationship are discussed, while some ount of production methods is given, with particular rence to the problems arising from small size. The ted problems connected with tolerancing, gauging and asurement are also considered.

ctave band-pass filter. Telephone Manufacturing Com- ny, Ltd., Sevenoaks Way, St. Mary Cray, Orpington, Kent. flet F.3540 describes an octave band-pass filter which vides means of separating the sound energy contained in one of the eight octaves in the range 37·5 to 9 600 c/s n that contained in the whole of the audio frequency range, ermitting the measurement of acoustic energy distribution h frequency.

as chromatograph. Beckman Instruments, Inc., Process ruments Department, 2500 Fullerton Road, Fullerton, ifornia, U.S.A. A 4-page brochure describes the new del 220 industrial gas chromatograph which has been cifically designed for the continuous, automatic analysis rocess streams, using a unique sampling valve and timing em.

ynchronous convertor. George Kent Ltd., Luton, Bedford- e. Publication 994 describes a new synchronous convertor ch has been primarily designed for converting small ct voltages into proportional alternating signals for easy t-free amplification; it can also be used for the phase- sitive rectification of alternating current, or for both poses simultaneously.

caler unit. General Radiological Ltd., 15–18 Clipstone eet, Gt. Portland Street, London, W.1. A leaflet describes type 1366A scaler unit which has been designed for use conjunction with a discriminator and a logarithmic rate- er as a control element in the operation of nuclear reactors.

ases and racks. Alfred Imhof Ltd., 112–116 New Oxford eet, London, W.C.1. New leaflets have been issued to oduce a large number of new items to a standard range of cases and racks and many new components to the IMLOK construction system.

Fog detector. Stone-Chance Ltd., Engineers, Crawley, Sussex. Details have been made available of an automatic fog detector. The basic principle employed is that of measuring the amount of light reflected from water particles suspended in the atmosphere.

Valve voltmeter. Airmec Ltd., High Wycombe, Bucks. Leaflet No. 168 describes the type 217 valve voltmeter which is a general purpose instrument suitable for measuring balanced, unbalanced and differential a.c. voltages in the frequency range 10 c/s–200 Mc/s, positive and negative direct voltages up to 500 volts, and resistances from 100 ohms to 100 megohms.

Thermistors. Gulton Industries, Inc., Metuchen, New Jersey, U.S.A. A new 10-page bulletin gives specifications and characteristics of wafer, rod, and bead thermistors. Each type of thermistor is illustrated with diagrams and charts indicating models and their corresponding characteristics and size.

Electrothermal heating tapes. Electrothermal Engineering Ltd., 270 Neville Road, London, E.7. A 4-page illustrated leaflet describes "Heat-by-the-Yard" electrothermal flexible and elastic heating tapes. The tape, which can be cut to almost any length, enables the user to apply heat to practically any pipe, vessel, valve, etc., just by cutting a suitable length of tape from the dispenser and fixing the insulated terminations.

Ratemeter. General Radiological Ltd., 15–18 Clipstone Street, Gt. Portland Street, London, W.1. A leaflet describes the type 1161B general purpose ratemeter for use in measuring count rates over a variable range against time, and designed to work with standard probes and recording gear.

Electronic and nucleonic equipment. General Radiological Ltd., 15–18 Clipstone Street, Gt. Portland Street, London, W.1. This firm have issued a series of leaflets which describe the following instruments: General purpose ratemeter (Type 1161B); Portable fast neutron scintillation monitor (No. NIS12); Geological survey unit (The Red Box). This instrument is intended for the detection and measurement of gamma radiation.

Notes and comments

rnal of Ultrastructure Research

new scientific journal has been announced entitled: *rnal of Ultrastructure Research* which is to be edited by Fritiof S. Sjöstrand and Dr. Arne Engström, both ociated with the Karolinska Institutet, Stockholm.

he purpose of the *Journal* will be to assemble, in one dium, papers dealing with the ultrastructure of the ele- ntary structural as well as functional components of cells l tissues. The first volume, priced at $15.00, will consist four issues. Manuscripts by Ebba Andersson, A. J. lton, R. Ekholm, E. Faure-Fremiet. D. Ferreira, A. Frey- ssling, B. Vincent Hall, E. L. Kuff, M. G. Menfee, and Rouiller have been accepted for publication in the initial ies.

Further information can be obtained from the editorial offices of the *Journal*, Department of Anatomy, Karolinska Institutet, Stockholm 60, Sweden. Subscription orders should be sent to the publishers, Academic Press Inc., 111 Fifth Avenue, New York 3, New York, U.S.A.

The Combustion Engineering Association

Economies in fuel, if real gain is to be achieved, must be practised on a nation-wide scale. The Combustion Engineering Association seeks to secure this by bringing together all interested parties to ventilate their problems and difficulties and benefit from the views and experiences of others. Membership of the Association is open to all industrial fuel users; consulting engineers; manufacturers of combustion and ancillary equipment; heating and ventilating engineers, and distributors of solid and liquid fuels. A Conference is being held by the Association on 5 and 6 November at Harrogate at which will be examined in detail the Third Progress Survey of the National Industrial Fuel Efficiency Service. Details may be obtained from the Association, 6 Duke Street, St. James's, London, S.W.1.

Teaching aids

A teaching aids sub-committee has recently been formed by the Science Masters' Association to collect information concerning teaching aids and prepare lists of these for circulation to its members. It would be appreciated if representatives of industrial organizations would supply the Committee with details of any booklets, wall-charts, models, showcases and filmstrips they may have which would be of use to schools. The details should include the name of the teaching aid, type and cost and be sent to the Secretary, 24 Coniston Road, Bromley, Kent.

Paul instrument fund grants

The Paul Instrument Fund Committee, composed of representatives of the Royal Society, the Physical Society, the Institute of Physics and the Institution of Electrical Engineers, was set up in 1945 "to receive applications from British subjects who are research workers in Great Britain for grants for the design, construction and maintenance of novel, unusual or much improved types of physical instruments and apparatus for investigations in pure or applied physical science."

A grant has been made from this fund to Dr. E. T. Hall, senior research officer at the Research Laboratory for Archaeology and the History of Art, Oxford, for the construction of an apparatus with which magnetic measurements may be made of archaeological material and for the development of an instrument for applying the method of neutron activation analysis to archaeological problems. A grant has also been made to Dr. C. M. Smyth and Mr. F. Y. Poynton (Northampton Polytechnic, London), for continuation of the construction of an ultrasonic microscope for which a grant was made in December 1954.

Formation of data-processing section

The Society of Instrument Technology is setting up a special section to cater for the current interest in data-processing systems. This section will begin to hold meetings in London this Autumn and the following four papers are scheduled for the first session: 10 October—A system for handling wind-tunnel data, by J. F. M. Scholes; 14 November—A digital plotting table, by J. Morrison; 28 January—Digital codes and coding, by M. P. Atkinson; 29 April—A joint meeting on scanning and logging, with papers D. H. Whiting and J. Dunkley and J. Churchill.

Initial emphasis will be on systems for handling experimen data, and for industrial monitoring and control. The secti will be concerned with system design as well as with t detailed design of equipment; it will also deal with the u and organization of systems and with design-study work.

Membership of the section is open to all members of t Society, who may also join the other special group, t Control Section. Members receive the quarterly "Tran actions" of the Society, in which the data-processing pape will be published. Further information may be obtain from the Secretary, Society of Instrument Technolog 20 Queen Anne Street, London, W.1. Anyone interested contributing to the activities of the section should write the Section Secretary, W. T. Bane, 137 Kenilworth Cou London, S.W.15.

Erratum

In the special article on the Physical Society's Exhibiti which appeared in the July issue of this *Journal*, a referen was made to interference filters manufactured by Barr Stroud Ltd. We have been asked to point out that auxiliary filters normally supplied with this firm's prod are based on optical quality glass and not gelatine.

British Journal of Applied Physics

Contents of the October issue

ORIGINAL CONTRIBUTIONS

Contact stresses in toroids under radial loads. By H. Fessler and E. Ollert

The application of a transient method to the measurement of the thermal c ductivity of rocks and building materials. By G. Gafner.

The measurement of Meyer hardness and Young's modulus on the Rockwell machine. By D. K. Mackenzie and T. P. Newcomb.

High-temperature tensometry and its application to amorphous polyethyl terephthalate. By E. L. Foster and H. Heap.

A method of measuring the thermal constants of granular materials. By T. S. Thomas.

Measurement of the diffusion rate of hydrogen in nickel. By A. G. Edwards.

On the screen brightness required for high resolution operation of the electr microscope. By A. W. Agar.

Non-linear forced vibration of a stretched string. By E. W. Lee.

High vacuum shaft seals, flanged joints and the gassing and the permeability rubber-like materials. By R. H. V. M. Dawton.

NOTES AND NEWS

Correspondence

The γ-ray scintillation spectrometer. From D. H. Peirson and P. Iredale.

Scaling laws for space charge dynamics. From E. R. Harrison.

New Books

Notes and comments

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CONFERENCE REPORT

Instruments for use in occupational hygiene

By C. N. DAVIES, D.Sc., F.Inst.P., London School of Hygiene and Tropical Medicine, Keppel Street, London

Eight papers were read at the Conference reported in this article. The subject-matter included the planning of sampling programmes for maintaining a healthy working environment in industry and the assessment of incompletely defined atmospheric pollution from observations on human subjects. Instrumentation for safety in mining was described with special reference to gas and dust explosions, pneumoconiosis and non-destructive testing. Details were given of the technical precautions needed when taking chest X-rays for the clinical assessment of pneumoconiosis.

The assessment of samples of toxic vapours, secured with a simple hand pump, was covered in a paper which surveyed recent improvements in absorption methods; the more complex apparatus required for absorption spectrophotometry over a wide range of wavelengths was also reviewed. Safety in the presence of atomic radiations was considered in two papers, one dealing with instruments for measuring and monitoring radiation and the other with instruments used to aid clinical diagnosis of the consequences of human exposure.

British Occupational Hygiene Society held a Conference his subject in London on 16 and 17 April, 1957. Industrial onnel are exposed to numerous hazards from the materials ch they handle, hence both operational routines and the kers' environment need to be carefully controlled. The ference was devoted to instruments specially adapted to prevention of accidents and illness due to dust, poisonous es and vapours, radiation, explosions and mechanical ire. A broad view was taken throughout the proceedings, by the authors and by those who entered into discussion them. General principles, the strategy of application its reaction upon design featured as strongly as technical il, and a striking characteristic was the enormous range complexity in the instruments mentioned, which included tronic devices containing hundreds of valves at one end he scale, and the simplest possible hand-pump sampler at other. When faced with certain intractable problems the t ingenious tools of the physicist failed to give an rpretable answer and recourse was necessary to direct ervation on the human subject. Assessment of the state health of a human being in terms of meter readings was sible only in the most elementary circumstances.

he first paper dealing with "Sampling programmes and pling instruments," by Mr. R. C. TOMLINSON (National l Board), discussed the general problem of representative pling, illustrating the conclusions with examples from dust pling practice in coal mines. A sampling programme a function of the environment, the information required the instrument chosen for the job; the choice of instru- nt, in turn, was a function of the environment, the infor- ion required and the programme envisaged. Programme instrument were therefore interdependent, although the al problem encountered was to determine the programme ig given the other factors; this aspect, therefore, was given t attention in the paper.

MPLING FOR MEASUREMENT OR FOR CONTROL

nvironmental conditions could only be determined by a t sampling programme from which an efficient sampling cedure could be evaluated. Variations could be analysed a position effect, a time effect, a position-time interaction an overall random fluctuation. An examination of rds of many coal dust samples showed that patterns of variation which persisted from day-to-day were usually outbalanced by day-to-day variation of working conditions, thus emphasizing the value of an average taken over the daily working shift and the value of the long-term over the snap dust-sampling instrument. The information required from sampling had to be defined and fell naturally under the headings of measurement and control. If the dust conditions at a working place were so bad that one's neighbour could not be seen, very little sampling was needed to ascertain that the permissible standards were being outraged. To measure accurately such heavy dust concentration within a defined limit would be difficult and unnecessary. Control sampling, which was concerned only to detect whether conditions were different from standard, would obviously entail less work.

Measurement sampling was necessary to find out sufficient about conditions in which men worked and their reaction to them, for a reliable association to be established between dust exposure and the risk of resultant disease. Until recently the only reliable instrument for measuring dust was the conventional thermal precipitator which had to be operated for a length of time related to the dust concentration; failing this, the slides were either too sparsely or too densely coated for accurate counting. The instrument could only give information about averages over its natural time period. The new instruments averaged over a much longer period and therefore saved labour, but they were unsuited to exploring short-term fluctuations. This example illustrated a general "uncertainty" principle of instrument design, and of the design of sampling programmes, that a gain in efficiency in one way was only obtained at the expense of less precise knowledge of certain other factors.

The main distinction between control and measurement sampling was that the former need not be tied to the individual worker's environment. It sufficed, for example, to exercise dust control over a coal-face by measurements taken at the return end. Control sampling implied the existence of a standard which had to be stated in terms which were compatible with the sampling procedure. Ambiguity existed when there was merely a bald statement of maximum allowable concentration because this avoided issues such as the period over which it was to be averaged. Such problems as the accumulation of explosive gas or the prevention of fires were of a different nature to the inhalation of dust because they involved immediate dangers; the establishment of dust disease took many years.

ERRORS IN SAMPLING RANDOMIZATION

A sampling programme was necessary because it was not normally possible to keep a record of all conditions in which the men were working at all times. Selection was essential. In devising the programme the occurrence of both random and systematic errors had to be borne in mind. The former could be measured and reduced by increasing the number of observations. The latter errors, or bias, were eliminated if the sampling programme was drawn up on correct principles.

In measurement sampling, that is, the measurement of the environment of individuals, two procedures were possible. In the first there was systematic coverage of all times and operatives; a plan for this was drawn up and the order of procedure was then randomized to avoid bias. A difficulty might arise if the times of sampling were regular because the dust pattern could have periodicity due, for example, to meal breaks. This was avoidable by choosing sampling times at random with a specified number of time periods, as in the "Random Collier" method which was equally applicable to other statistical problems.(1) The other procedure for measurement sampling was to sample at fixed positions in a working space rather than in the vicinity of individual men. This was convenient and provided a good picture of the distribution of dust in the area. Unfortunately the results could not be used unless the pattern of the men's movements was known since they might spend a disproportionate amount of time in certain locations.

A control sampling programme sought only to find if conditions were safe in as economical a way as possible. Spot samples were of little value unless sufficient in number to give a shift average. The most satisfactory procedure for ascertaining if conditions were on the right side of a standard was not to take a prescribed number of samples, which led to a multiplicity of results in ranges of gross excess of defect, but to continue sampling only until enough information had been accumulated to arrive at a decision. Such a procedure for the approval of a coal face had been described.(2) A still better scheme, which had not yet been applied in coal mining, would be to use a preliminary series of samples, with all dust suppression measures in operation, to establish a norm and then to design subsequent monitoring with a view to detecting any deterioration calling for remedial action.

The choice of sampling instruments was primarily influenced by the desirability of working with shift-average concentrations of dust in mines. The average could be obtained as an integrated figure from continuous sampling, which was desirable for control, or from broken periods which might have to be associated with machine operation. Robustness and portability of the instrument were also decisive factors, especially for measurement sampling where the workman was followed. Control sampling lent itself to automation, especially if the standards were appropriately expressed. Instruments well on the road to automation were available but their linkage to the actual function of control was a matter for debate.

STUDY OF ATMOSPHERIC POLLUTION

Dr. P. J. Lawther (Medical Research Council) then spoke on "Some analytical and clinical methods in the study of atmospheric pollution." He said that chronic urban atmospheric pollution was suspect as an aetiological factor in the production of chronic bronchitis and lung cancer, while severe acute pollution, experienced during temperature inversions, was known to have a harmful effect on pati whose respiratory function was impaired by pulmonar cardiac disease.

In order to understand this problem it was necessar study concurrently the character of the polluted air and health of susceptible patients. Volunteer patients could exposed experimentally to gases and aerosols in a cham but the experiments had to be confined to the produc of effects which were rapidly reversible, such as bronchospa They could not be used to predict the behaviour of exposed to complex urban pollution over long peri because they tended to produce negative results wh exonerated rather than incriminated individual contamina Likewise the time taken for a guinea pig to die in an at sphere containing 500 p.p.m. sulphur dioxide bore a stri limited relevance to the plight of an old man with emphyse who was laid low with bronchospasm on a smoky day w the concentration of sulphur dioxide reached only 1 p. The study of the patient in his polluted environment preferred to the direct experimental approach, though latter had complementary value. The use of instru was therefore directed mainly to the determination of patient's environment and to the assessment of his cl status.(3, 4)

Reviewing the methods of measuring sulphur dioxide centration,(5) the author emphasized that 24-hour mean might not indicate the true health hazard; peak concen tions might be of much greater toxicological significanc enormous variations could occur over short periods (Fig. Automatic sulphur dioxide recorders were needed for work.(7)

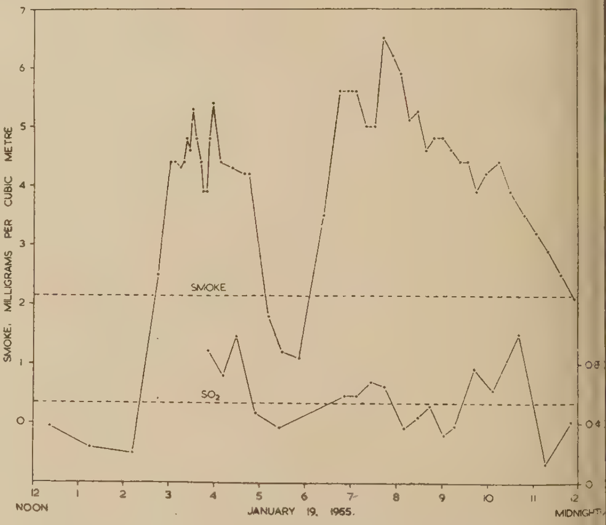

Fig. 1. Variations in concentrations of smoke and su phur dioxide on the roof of St. Bartholomew's Hospita E.C.1

Sulphur dioxide, however, was not the only har pollutant and the nature of the particulate contaminants revealed by the electron microscope,(8) was suggestive. T complicated structure enjoined caution in drawing conclus about the penetration and retention of particles in the lu since most existing knowledge in this field came from w on dusts in connexion with pneumoconiosis and associated with ideal, spherical particles.

MAN AS A SAMPLING INSTRUMENT

e main object of the study was biological and in spite of emarkable techniques of physical instrumentation it still ined advantageous to make a direct approach to the lem and use the object of the tests as both an indicator an answer. In California spinach and other plants, h were severely damaged by certain air pollutants, were erly used as specific test instruments. The Los Angeles og" had a notorious lachrymatory effect. In spite of an mous amount of analytical work the compounds respon- had not been identified with certainty and amidst the plex analytical machinery the proper object of the work, uman subject, was being used as an instrument to assess achrymatory power of suspected compounds. Carbon oxide, a pollutant from petrol-driven vehicles, could be rded with an infra-red analyser, but the interpretation of results was less certain than the estimation of carbon oxide in the blood of a man who had worked in the ronment in question.

a similar manner it had been found profitable to use ents with chronic bronchitis as instruments in an attempt etermine the circumstances responsible for their clinical rioration. In St. Bartholomew's Hospital a group of ents whose clinical condition had been followed for ral years was available for this purpose. Patients with nic bronchitis maintained that certain types of weather e them worse. They were therefore invited to write in a y a simple assessment of their condition which was later elated with records of atmospheric pollution (Fig. 2).

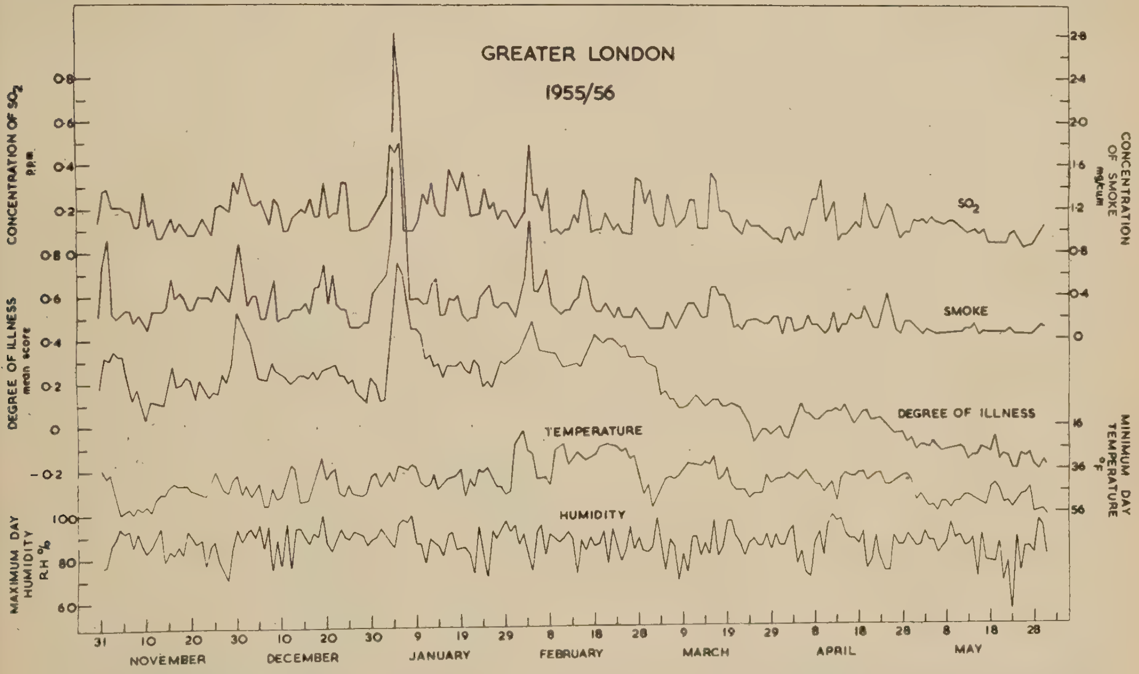

Fig. 2. Graph showing degree of illness of 180 patients in Greater London with chronic bronchitis plotted with smoke and sulphur dioxide concentrations, temperature and humidity

ose relationship was found between degree of illness and atmospheric content of smoke and sulphur dioxide in er, which ceased to exist in summer when temperature other factors seemed to assume control. This result was entirely dependent on atmospheric visibility and the riment had shown that attention must be directed rds pollution as distinct from fog. Wet fog, as such, did not have a marked ill effect on the patients. It was hoped that this use of the patient as an instrument would bear fruit and that the approach would not be scorned beside the complexity of modern instrumentation.

EXPLOSIONS IN MINES

The next paper on "Some instrument techniques in use at the Safety in Mines Research Establishment" was read by Mr. C. A. A. Wass (Safety in Mines Research Establishment). Explosions due to gas or dust, although rare, might have a devastating effect and were studied by instruments devised to examine the conditions of pressure, fuel movement and concentration before and during an explosion. Shock waves were photographed by the Schlieren method(9) using a rotating mirror camera(10) synchronized with a slotted rotating disk; the method was adequate for wave speeds up to 10 000m/s. A Courtney–Pratt camera(11) was used for self-luminous objects such as sparks. Image-converter tubes were used for very short exposure photography of flame kernels.

Propagation of a dust explosion depended on the blast ahead of the flame being able to disperse settled dust. The measurement of blast was achieved by recording the phase difference between sound reaching two receivers equidistant from a source on the opposite side of the mine gallery. The phase shift depended on the air velocity.(12) Another blast-meter employed strain gauges to measure the deformation of a steel reed exposed to the blast.

Explosion pressures, developed inside the casing of electrical equipment under test for use in gassy atmospheres, were measured by diaphragm gauge and optical lever(13) or by a piezo-electric gauge electrically damped to a long time constant.(14)

A device for dispensing a quenching agent ahead of an advancing flame front employed a thermistor but its use was limited by battery drain. A new approach to the problem resulted in a spring-loaded switch held open with nylon threads 0·005 m diameter; these softened enough to allow the switch to close within 15–20 ms of the arrival of flame.

Ignition of methane, followed by the ignition of coal dust, was the usual cause of major explosions. Air containing 5% to 15% of methane formed an explosive mixture and a legal obligation existed for checking methane concentration. Its estimation by the height of the flame cap in a safety lamp was being replaced by measurements with more accurate and sensitive methanometers. Some of these depended on the combustion of methane on a filament in a closed chamber and recorded either the fall in pressure, due to loss of oxygen, or the change in temperature. The latter method, with a compensating filament to balance out the effects of atmospheric changes, was sensitive if the apparatus was carefully maintained.(15) The principle of the Jamin interferometer had been applied to the measurement of methane concentration(16); atmospheric carbon dioxide and water vapour had to be removed.

PRECAUTIONS AGAINST DUST DISEASE

Pneumoconiosis, a disease caused by breathing dusty air, was the main health hazard in coal mines. It was controlled by working to approved conditions of dust concentration which necessitated constant monitoring with dust sampling instruments. Recent developments enabled the mean concentration to be measured over periods related to the working shifts, thus considerably reducing the labour of evaluating numerous short term samples. The instruments depended on thermal precipitation(17) and sedimentation(18) and were fully automatic. A further reduction of labour was afforded by an automatic scanning machine which counted and sized dust particles electronically, using signals from a microscope with an oscillating stage.(19)

Routine dust estimation by sucking the atmosphere through a filter paper and measuring the light transmission of the stain had been improved by designing an aspiration pump with a controlled stroke (Fig. 3). The pumping cycle allowed time for the coarse dust to settle out of the air before it was drawn through the paper. The stain was measured undergrou in a small densitometer operated from a miner's cap lamp, An automatic, long-running sampler had also been desig to work with filter paper. The manner in which respira dust became dispersed in the underground atmosphere being studied by radio-isotope techniques.(21)

One of the most dangerous forms of dust disease was cau by the inhalation of quartz particles which were encounte when driving new headings and sinking shafts throu various kinds of rock. The quartz content could be det mined by X-ray analysis, using a Geiger counter spect meter,(22) and by differential thermal analysis. Visible a ultra-violet spectrometry and a thermal balance were availa for estimating other minerals.

Contributions made to electron microscopy techniques studying dust included a "heat-stable" membrane which transparent to electrons yet would withstand temperatu up to 500° C in air so that carbon and organic parti could be oxidized on it.(23) Particles of quartz, dissol away by hydrofluoric acid, left behind a carbon "skin" wh had been deposited on the particle from hydrocarbon vap present in the vacuum pumping system.

NON-DESTRUCTIVE TESTING OF PIT GEAR

Metallurgical work was involved in the examination mine equipment and a range of testing machines, microsco and furnaces was available. Manufacturing and se defects were searched for by non-destructive testing te niques. The latter included magnetic particle and fluores crack detectors. Flaws in steel reflected ultrasonic wa (about 2¼ mc/s) and could be located by transmitting a pu and recording its reflection on an oscilloscope. Con with a large object was made with a probe using longitu waves; for testing chain links (Fig. 4) the curved surface

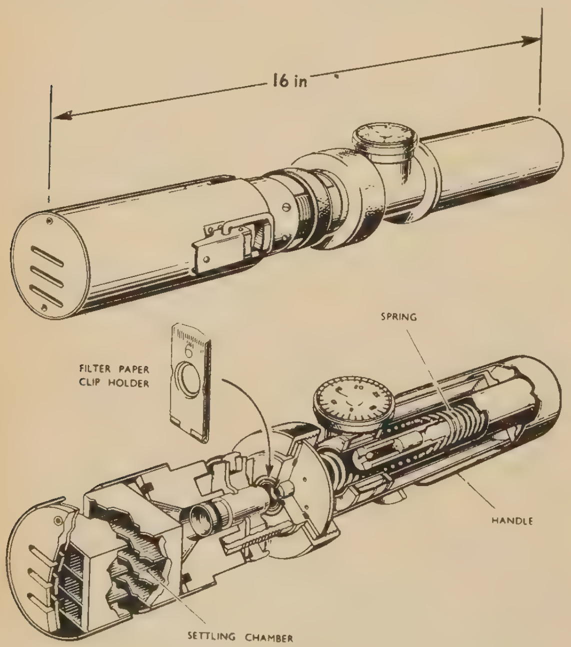

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Fig. 3. Safety in Mines Research Establishment automatic hand-pump

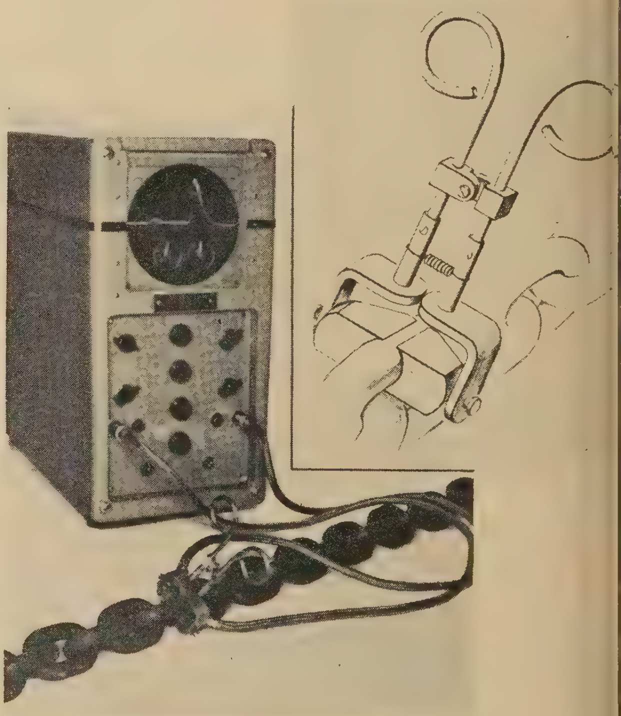

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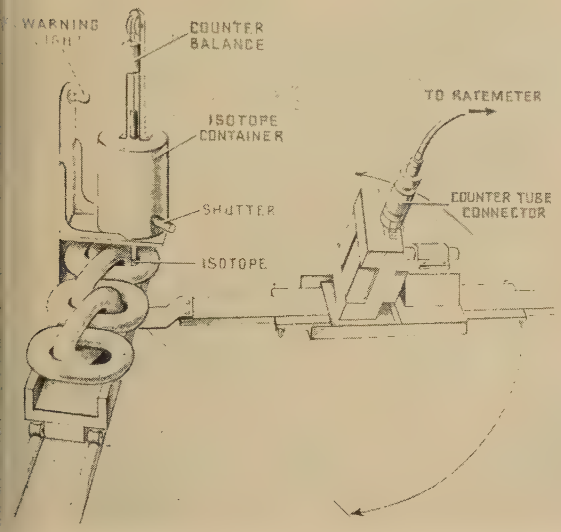
Fig. 4. Ultrasonic flaw detector showing (*inset*) probe heads applied to butt-welded chain links

ed upon a shaped Perspex block transmitting only verse waves which travelled round the chain link unless encountered a defect in the welding which would reflect of the energy back.

adiography with X-rays or a γ-ray emitting isotope could sed to detect flaws by photography, which was slow, or uoroscopy using an image intensifier. γ-rays transmitted ugh a metal specimen could be received on a counter would expose large flaws instantaneously. A 150 mc ce of ^{192}iridium had been used for inspecting chains 5)(24) in conjunction with a G.10 lead counter. A illation counter, with a sodium iodide phosphor, enabled ource strength to be reduced to 5 mc (^{170}thallium).



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ig. 5. Arrangement of isotope and counter tube for chain-link examination by radiography

t props which yielded under a given load were necessary erground for roof control. Their yielding was formerly rmined by friction pads of aluminium alloy, but this type to be withdrawn from use because of the frictional king hazard associated with aluminium. Frictional perties in other materials had been determined by strain ges attached to a strip of aluminium interposed between specimen and the straining head of the machine.

CHEST X-RAY AS AN INDEX OF DUST DISEASE

r. P. J. Chapman (National Coal Board) dealing with edical indices of coal workers' pneumoconiosis," stated it was now accepted that the disease was due to inhalation ust particles small enough to lodge in the lungs and that medical index representing the state of disease could be ted to the degree of exposure to dust the importance of ing dust conditions could be predicted. The choice of a ical index of disease was difficult because the develop- t of pneumoconiosis was so slow and diagnostic tech- es had changed over the last twenty or thirty years.

the past, indices based on the time elasped from first nosis or on the onset of grave disability had been used out success. Blood sedimentation rate and changes in stituents of the blood had been found to possess doubtful ificity. In 1916 the idea originated in Johannesburg the chest X-ray provided the most reliable indication of the severity of silicosis. It was this suggestion which had been followed up with pneumoconiosis and had led ultimately to the International Roentgenological Classification of Pneumoconiosis, published by the International Labour Office in 1953.

The consistency of observers' classifications of X-ray films had been extensively investigated by the Pneumoconiosis Research Unit and had yielded results justifying the assessment of a coal worker's disease by his radiological index, using the International System. It was important that X-ray films for this purpose should be prepared by a controlled technique; failing this, errors of classification were likely, even when they were read by experienced persons. The amount of blackening produced on the film was proportional to the quantity of X-radiant energy falling on it; this was expressed as the product of the current in milliamperes and the time of exposure in seconds. The usual procedure was to vary only the time, thus controlling the amount of radiation falling on the patient but taking no account of what passed through him and reached the film. A system which controlled the amount falling on the film and producing blackening had obvious advantages.

X-RAY EXPOSURE METERS

There were two ways of doing this. One was based on the intensity of light produced by a fluorescent screen between the patient and the film, and the other on the degree of ionization produced by the X-rays in a chamber placed in the same position. The former system used a photocell to provide current for switching off the X-rays; it featured in mass miniature radiography units. The latter, or Iontomat,(25) terminated the exposure when the ionization in the chamber had reached a certain level.

It was important that the wavelength of the radiation which ionized the air in the chamber should be the same as that affecting the emulsion of the film. The ionization chamber had plastic or aluminium walls, 1 cm apart, coated on the inside with vaporized lead. In between the walls was an insulated electrode, metallized on one side only, which defined the measuring area, but was sufficiently translucent not to cast a shadow on the film. Only radiation actually passing through the patient traversed the measuring area. The functioning of the device is illustrated in Fig. 6. Ionization current from the chamber (6) discharges the condenser (4) until the thyratron (7) strikes and breaks the tube circuits *via* relay (8). The density of films produced is controlled by the charging potentiometer (5). This method of control compensated for variations in the thickness of the patients' chests.

Variations in the speed of the photographic emulsion prevented full advantage from being taken of this system of exposure control.(26) Results were satisfactory if the emulsion could be standardized within a speed range of ±5%; failing this, test strips had to be exposed in order to decide the exposure setting. For test exposures a step wedge was made of aluminium sheets of equal thickness. Exposure was made through this so that different parts of the film received radiation which had traversed one or more of the aluminium sheets. Alternatively, a trial exposure on a human subject could be made, though this involved his receiving a dose of radiation without medical justification. The possibility of constructing a "synthetic" chest was being explored.

It was important to use a short exposure in chest radiography to avoid blurring due to heart and other movements. An intensifying screen coated with calcium tungstate, which fluoresced, gave marked reduction in exposure time although only about 3% of the X-ray energy falling on the screen was converted into light. The screens were used in pairs in the cassette, one on each side of the X-ray film which was coated with emulsion on both sides. Test wedge exposure checks were necessary.(26)

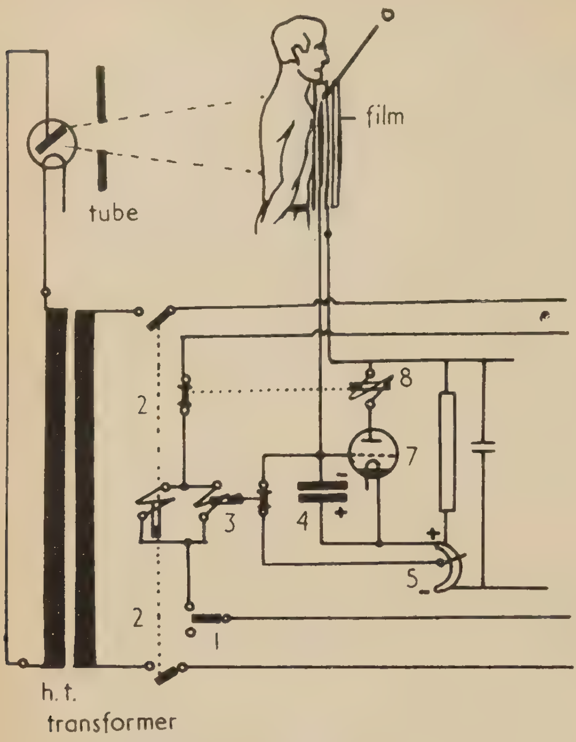

Fig. 6. Iontomat ionization chamber (by Sierex Ltd.) system of controlling X-ray exposure time

INSTRUMENTS FOR RESPIRATORY PHYSIOLOGY

Even with controlled exposure considerable variation in the quality of the radiograph could result from faulty development technique. Time and temperature were important and a mechanical processing unit had advantages.(27) Care was needed to obtain exact repetition. Attention had to be given to uniformity of radiation intensity and of processing, over the entire area of the film, and to the replenishment of developer in relation to the quantity of film processed. Other forms of medical index for disease had been investigated recently besides the radiological one. The most characteristic physiological symptom of the early pneumoconiotic was breathlessness. It had been shown that the effectiveness of breathing depended less on the volume of air which could be moved by a single, maximum effort than on the volume moved in a given unit of time. This was associated with the pumping or bellows action of the lungs which suffered impairment. An apparatus designed by Gaensler(28) was capable of assessing a single, forced exhalation for this purpose (Fig. 7). A low inertia spirometer was exhaled into by the subject, after a deep breath. The volume expired was recorded on the drum for any pre-set time period up to three seconds. As the spirometer bell rose the cord attached to the counterweight caused the large Perspex wheel to rotate and actuate timing switches.

It was possible to distinguish, from the instrumental indication, between breathlessness due to disease of lung tissue and that caused by an obstruction of the air passages. the first case the percentage of total volume expired in given time was not reduced, but there was a diminution the total amount of air exhaled. In the latter circumstanc there was no reduction of total volume, but the rate of a flow and percentage of total volume delivered in the measure time fell markedly. A new instrument, due to Dr. B. Wright, contained a mechanical flow meter which recorde on a dial the actual maximum rate of air flow attained.

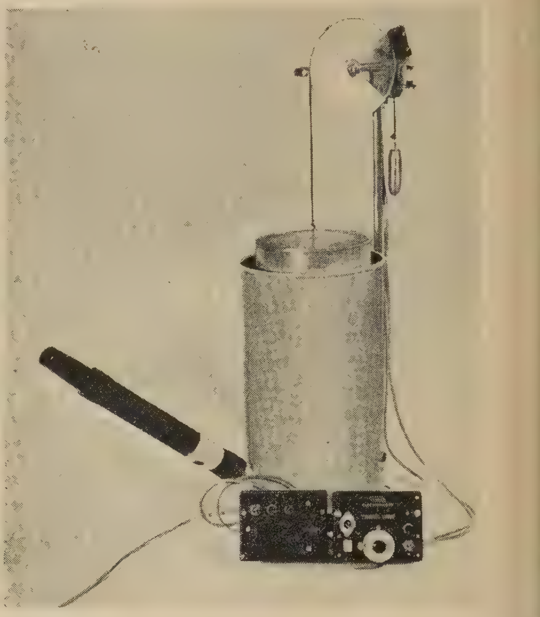

Fig. 7. Gaensler spirometer for measuring rate of ai flow in a single exhalation

ESTIMATING TOXIC VAPOURS

In his paper "Field tests for toxic substances in industri atmospheres" Mr. B. E. **Dixon** (Department of the Gover ment Chemist) considered simple inexpensive apparat requiring the minimum of skill in operation. The tes had to be reliable and at the same time sensitive to a co centration of not more than half the toxic threshold limi defined as the maximum average concentration to whic workers might be exposed for an eight-hour working da without loss of health. A test should be capable, also, measuring up to about 4 times the toxic threshold. Since test was usually employed in the environs of a chemical plan or in a room where a certain process was carried out, specifici was not essential, but freedom from interference by oth gases likely to be present had sometimes to be allowed fo An accuracy of about ±20% would usually suffice. Con pliance with these requirements, together with the fact tha as a rule, only a very small amount of the toxic contamina could be collected, practically necessitated the adoption colorimetric techniques.

A standard form of hand-pump sucked 126 ml of t atmosphere through the apparatus. This might be a te paper in a holder attached to the pump or a bubbler followe by a trap. The impregnated paper developed a stain whic was compared with a chart of standard stains; for the bubbl method a comparison tube of standard solution was use ther method was to suck the air through a tube con-ng treated silica gel. The length of the column becoming ıed was taken as an index of atmospheric concentration ıis case. Occasionally it was not possible to produce a ı directly, in this manner, and two successive operations ›parate tubes were necessary; mercury and its compounds ided an example.(29) Improvement of performance must involve an increase in delicacy or complication, and ns to this end were therefore confined to application of absorption theory, the discovery of new reactions and :ovement of test paper, charcoal and silica gel.

bsorption processes were not usually of a simple physical ıre; the chemical reaction, as a rule, influenced the rate bsorption. A resistance to mass transfer existed mainly ıe gas-liquid interface and devices which ensured a rapid wal of this surface enhanced the rate of absorption. orption at the surface of a porous plate was extremely e,(30) far more so than in the region of foaming liquid e the plate. Devices which increased the length of path ubbles or stirred the absorbing liquid above the feed ce were therefore of little value. An impinger had high absorption efficiency(31); the gas jet was blown at high city against a plate covered with liquid and the film of d in the contact region was turned over very rapidly.

ıere was a lack of information on the optimal rates of flow and particle size for absorption on silica gel. This a partially dehydrated form of polymerized colloidal ı having an enormous surface area up to several hundred ıre metres per gramme. The pores were probably inter-ıected channels and the flow of gas was complicated by rption phenomena and reaction within the pores. Staining lter paper was superficial and stains were usually examined eflected light. The surface layer of test papers therefore ired careful protection.

s well as with the hand-pump, manual sampling could be carried out with an aspirator bulb and valve which a slow and perfectly steady suction. Too rapid a flow, as might be produced by mechanical pumps, involved sk of incomplete absorption in bubblers or of patchy ing on papers; intensely coloured pinholes resulted from nelling of the flow through the larger pores. Timing localization of sampling was important and should be idered in relation to the activities of the workers whose ıre was suspected.

ABSORPTION SPECTROMETRY

paper on "Instruments for absorption spectrometry" read by Mr. R. A. C. Isbell (Hilger and Watts Ltd.). ı instruments used entirely different components depend-whether they covered the ultra-violet (200–400 mμ), le (400–700 mμ), or infra-red (0·7–40 μ) regions of wave-h. The majority of organic chemicals, including the : complicated, could be identified by their energy absorp-in one or other of these regions and some could be ıated. Where specific absorption in the visible range was ng a reaction could often be employed to produce a ıred compound or complex which could be assessed by rimetry or absorptiometry; these techniques were also for the inorganic anions found in the body. All instru-ts comprised three basic sections: a light source, a means plating a particular wavelength, and a detector associated a measuring device.

ıe barrier layer photocell was the simplest detector. It isted of an iron plate coated with selenium upon which a sparent metallic film was deposited; the iron plate formed one electrode and a Wood's metal ring on the sensitive surface the other. The current produced was not proportional to the incident light flux unless the intensity was low and the electrical resistance of the meter was below a few thousand ohms. There was also a risk of fatigue and the development of dark current. Some of these disadvantages were overcome by using two barrier layer cells balanced against one another from a common light source so that the absorption of a sample placed in the way of light reaching one cell was compensated by an optical reduction in the intensity of the other beam (Fig. 8).

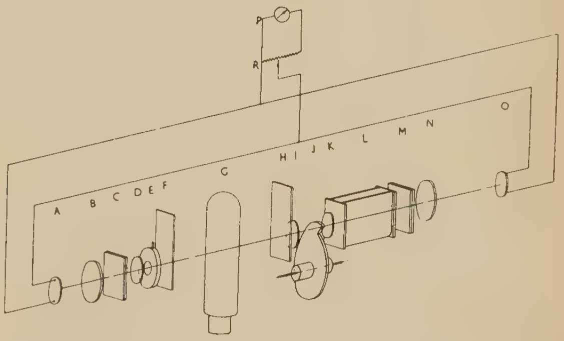

Fig. 8. Diagram of optical system and photocell circuit of Spekker absorptiometer (by Hilger and Watts Ltd.)

A, photocells; *B*, lens; *C*, spectrum filter; *D*, window; *E*, iris diaphragm; *F*, heat absorbing filter; *G*, lamp; *H*, heat absorbing filter; *I*, window; *J*, measuring disk; *K*, lens; *L*, cell for liquids; *M*, spectrum filter; *N*, lens; *O*, photocell; *P*, spot galvanometer; *R*, sensitivity control.

In this type of instrument linearity of response was unimportant and the effects of fatigue and dark current drift were reduced. The vacuum type of emission photocell was capable of giving greater sensitivity than the barrier layer cell and could be coupled to an electronic amplifier.

Isolation of a waveband could be achieved with filters, the sharpest selection being given by the interference type which picked out a range of 1 mμ or less. The principle employed was that of the Fabry–Perot etalon. Two partially metallized glass plates were separated by a transparent medium so that white light was filtered into a series of orders at various wavelengths depending on the optical path between the plates. A supplementary filter was used to remove unwanted orders. The limiting factor was white light transmission through pinholes, which might be $\frac{1}{2}$% in comparison with 25–30% at the peak. Although the transmission at the desired wavelength was high, the band width was so small that only a very low intensity of light reached the photocell. A narrow-band supplementary filter was necessary to reduce the stray light background and further reduced the peak transmission. A prism type monochromator (Fig. 9) was free from these disadvantages.

In the ultra-violet region a tungsten filament in a glass envelope was a satisfactory source down to 350 mμ below which a hydrogen arc in fused silica was required. Quartz or fused silica optical components were needed down to 200 mμ. A high quality original grating made a good monochromator. A major part of the cost of such an instrument was due to electronic amplification and the stabilized power supply. By changing lamps and photocells the same apparatus could be used for both the visible and ultra-violet wavelengths. Attachments could be made for flame spectroscopy. In these instruments individual settings of a potentiometer were usually read after backing off the potential drop across a high resistance due to the photocell current. Chart recorders, however, were under development.

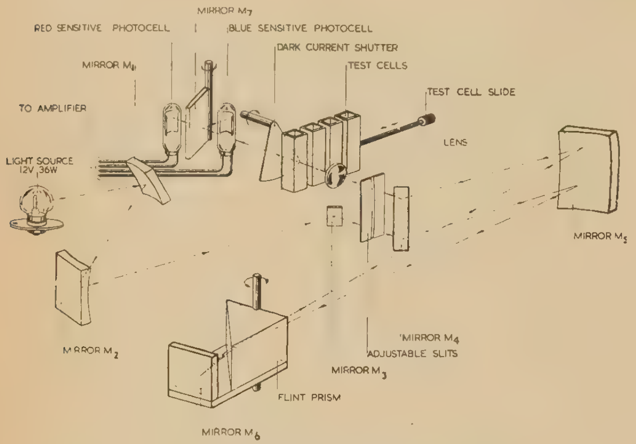

Fig. 9. Optical system of type SP600 visible spectrophotometer (by Unicam Instruments Ltd.) using a glass prism monochromator and vacuum type photocells

INFRA-RED INSTRUMENTS

Infra-red recording spectrometers were expensive but were coming into use in medical research. In general, infra-red spectra were complicated and showed narrow absorption bands. The location of a band was liable to be shifted according to the configuration of the molecule as a whole. A recording instrument capable of scanning a range of wavelengths was therefore essential. The double beam system was used to eliminate atmospheric absorption. The Nernst filament was a good source. This was a thin porcelain-like rod, containing rare earth oxides, which conducted electricity and could be raised to incandescence by a current.

Quartz and glass prisms were suitable for only the lowest wavelength. Most commonly used was sodium chloride which transmitted out to about 16 μ. Potassium bromide, calcium or lithium fluoride, and caesium bromide were also used. These prisms were very expensive to make, being softer and more difficult to work and polish than glass; some were hygroscopic and deteriorated if surface condensation was allowed to take place. Diffraction gratings giving a very high dispersion over a short wavelength range were now available.

No photocells were suitable for the infra-red region, but a semi-conductor cell of lead telluride functioned out to 6 or 7 μ. A thermopile was the usual form of detector. A fast response could be achieved by good design (30 ms), thus enabling a light chopper and alternating current amplification to banish the drawbacks of d.c. circuits.

CONTROL OF HEALTH RISK DUE TO RADIOACTIVITY

In his paper on "Instruments and their use for the control of ionizing radiation in laboratories" Mr. B. S. Smith (Atomic Energy Research Establishment, Harwell) opened by reviewing the permissible doses for external and internal radiation. The criterion adopted in assessing these doses was that no appreciable bodily injury would be caused to a person receiving them at any time during his lifetime.(32) For external radiation the basic permissible weekly dose for whole body exposure was 300 mrems in the lens of the eye, the gona and the blood-forming organs, or 600 mrems in the sk Some relaxations were permitted for limited portions of body, the main being 1500 mrems/week to the hands, f and head. Restriction of the integrated amount receiv was now expected to be made in addition to the above r limits. The permissible dose for internal radiation was c culated from the figures for the maximum permissible bo burden and the maximum permissible concentration in and water. The results varied for the different radio-isotop These levels were given in microcuries for body burden a in microcuries per c.c. for the concentration; they could, course, be translated into mass units.

It had been shown that by keeping the surface contaminati of a laboratory below

$$10^{-5}\ \mu c/cm^2 \text{ for } \alpha \text{ activity}$$
$$\text{and } 4 \times 10^{-4}\ \mu c/cm^2 \text{ for } \beta \text{ activity}$$

the inhalation of resultant dust in the atmosphere and external radiation received from the surfaces would not le to a violation of the above recommendations(33); relaxati factors of 10 or 100 were allowed in certain favoura conditions. This provided a basis for monitoring.

Instruments for monitoring should be designed to "f safe." Lightness and rapidity of response were mo important than high accuracy, an error of 20 to 100% oft being acceptable.

The definition of the Roentgen was based upon absorpti and ionization by secondary electrons taking place in a This requirement was met by having the walls of the char made of a material having a mass absorption coefficient equ to that of air. Such an instrument is shown in Fig. 10 contains 300 c.c. of air at 6·5 atmospheres pressure and

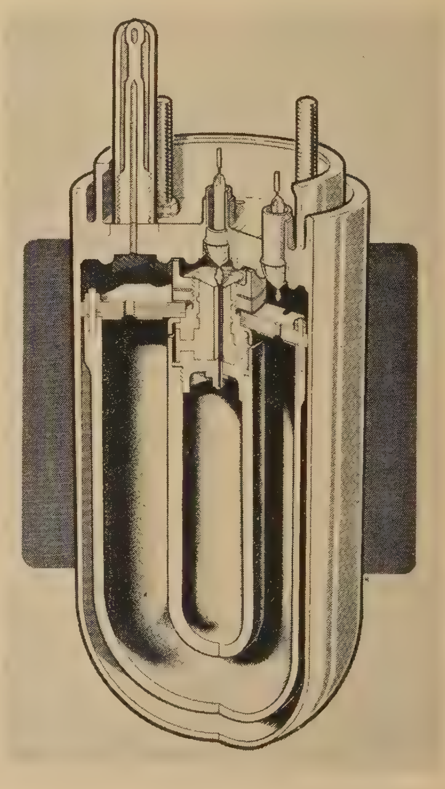

Fig. 10. Cut-away section of air-wall ionization chamber

ılded graphite walls giving air wall characteristics. For
ly purposes a simpler type of chamber was adequate,
g graphited bakelite walls; these were used in portable
ation monitors which might have built-in beta sources
checking their performance.

TYPES OF RADIATION COUNTERS

n gas counters, as in the ionization chamber, the inter-
on between the incident gamma rays and the wall was
trolled by pair production, Compton scattering and photo-
tric absorption. Ionization of the gas was produced by
h recoil electron. In the Geiger counter the strong
ecting field caused further ionization by collision yielding
ulse of current which was independent of the primary
ization due to the recoil electron. In a proportional
nter the collecting field was only high enough to increase
primary ionization by a factor of two or three.

Geiger counter was about ½% efficient for detecting
otons of 1 MeV energy; provided the cathode was made
low atomic number material its efficiency was nearly
portional to the energy of the incident photon over a
ge from 0·3 to 2·5 MeV. This feature allowed such
nters to be used for measuring milliroentgens independent
the energy of the gamma rays. The Geiger counter was
rly 100% efficient for beta rays having enough energy to
netrate the cathode wall. Proportional counters were used
en different types of radiation had to be distinguished.
e suitable for neutrons had been described.(34) Coupling
counter to a loud speaker was useful when operating a
nitor as a watch dog or when searching for contamination.

scintillation counter comprised a substance which emitted
ht when exposed to alpha, beta, gamma or neutron radia-
n in proximity to a photomultiplier tube which was
sitive enough to detect the absorption of a single quantum
the scintillator. The electron pulse could be made pro-
rtional to the absorbed energy.

For α-particles zinc sulphide phosphors were commonly
d. Good discrimination against β-particles was obtainable
ce a phosphor which was just thick enough to absorb
st of the α-energy was still fairly transparent to β-energy.
sodium iodide crystal could be arranged to produce light
lses of intensity related to γ-ray energy against a back-
ound due to radiation which had undergone Compton
ttering. By using large crystals γ-ray spectrometers had
en constructed which were valuable analytical tools for
asuring one isotope in the presence of others.

MONITORING TECHNIQUES

Photographic films were now used universally for personal
nitoring. The blackening was proportional to the energy
sorbed in the silver bromide; since the photoelectric
sorption of silver was much larger than that of air the
ckening per roentgen increased with the photon energy
wn to the K level of silver at 25·5 KeV. A film calibrated
h γ-rays therefore overestimated exposure to 100 KeV
liation by a factor of three. By using film between cadmium
d tin filters, each 1 mm thick, a roughly uniform response
exposure in roentgens was achieved over the range 0·1 to
MeV. Thermal neutrons were monitored by blackening
e to γ-rays when the neutrons were captured in the cadmium
er. Variations in the sensitivity of different batches of
ulsion necessitated calibration of the photometer scale by
t exposures.

Air monitoring was carried out by aspirating air through
er paper which collected dust resulting from the handling
of unsealed radioactive materials. The paper was estimated in a counter but biological significance could not be assessed without chemical identification. Physical methods of doing this were (1) measurement of rate of decay, (2) measurement of absorption curve of β-radiation, and (3) measurement of γ-ray spectrum.

The situation was complicated by the masking effect of the natural radioactivity in air which might be 10 to 100 times greater than that due to a toxic air contaminant such as plutonium. By delaying counting for two days the natural count subsided and allowed the longer lived plutonium to be detected. Natural activity was attached to particles much smaller than those carrying plutonium which had been shown in some instances to be a few microns in diameter. Selection by impactor techniques was then possible.(35, 36)

Control of the routes of inhalation and ingestion was the normal procedure for controlling the body burden of workers using radioactive materials. The various stages of the intake route were subject to uncertainty, however, and it was desirable to measure the energy spectrum of the emitted radiation and, by means of phantom studies, to assess the individual radioactive isotopes in the body.(36) The minimum detectable burden of radio-caesium was only about 10^{-5} of the permissible level so that there was no difficulty about finding the present level of radio-caesium in a population which had arisen from weapon debris. This development was due to the availability of large sodium iodide crystals and photomultipliers for scintillation counters.

The Conference terminated with a paper by Dr. T. E. Graham (United Kingdom Atomic Energy Authority, Windscale) on "Diagnostic aids in radiation medicine." After outlining the biological effects of radiation he explained how the figures for maximum permissible levels of radiating substances were arrived at.

External radiation was controlled by the portable γ-ray monitor, the pocket dosimeter and the film badge. These devices were adequate for checking repair and maintenance work on atomic reactors. The dosage was limited by strict timing, the rotation of personnel and the employment of unskilled labourers from non-active areas.

EXPOSURE TO NEUTRONS

The detection of neutrons was accomplished by absorbing them in substances, such as boron, which had a high capture cross-section. The isotope^{10} B formed an unstable nuclide with the captured neutrons which gave off an α-particle. A proportional gas counter filled with boron trifluoride was used in conjunction with a scintillation counter. It was necessary to slow the neutrons down, which could be done with Perspex, and boron and the scintillator could be incorporated in the plastic. Very fast neutrons ejected protons from hydrogen and these, again, could be counted directly.

A film badge for neutrons could incorporate a nuclear emulsion, loaded with boron, which recorded α-tracks, or an iridium foil which generated β-rays under neutron irradiation. Unfortunately ^{14}I was rather short lived for this purpose. The hazard from neutrons was usually confined to discrete beams of particles emerging from known places. Visual observations were often necessary, however, and exposure of the eye was dangerous. Perspex goggles only protected against sources of moderate energy.

CRITICALITY ACCIDENTS

The most dangerous hazard in radioactive work was the accidental attainment of criticality. Fissile elements, notably

^{239}Pu and ^{235}U, had a critical mass beyond which even a few atoms might initiate uncontrollable disintegration. Shape, chemical nature, surrounding materials and purity all affected the value of the critical mass. When a surplus of neutrons was available from these spontaneous emitters to cause more and more fissions the assembly became supercritical. In a time measured in microseconds great and increasing heat, light and all kinds of radiation were given off and melting, vapourization or explosion followed, according to circumstances. Should an atomic reaction become uncontrollable in this way persons in the vicinity might receive damaging doses of radiation. Three such episodes had been reported in America and there were reports of one in Russia.

Precautions to be taken in experimenting with critical assemblies should include shielding, remote handling machinery and wide dispersal of personnel. Static monitoring instruments should be installed so that in the event of an accident the extent of exposure could be gauged. Normal instruments might go off-scale in which case information could be obtained from the induced activity in surrounding structures. A high neutron flux would result in ^{24}Na being formed in the body of an exposed person from ^{23}Na by neutron capture. Serum and urine sodium could be used as an index of exposure. The contents of a victim's pockets might also provide clues as to dosage. Gold and silver articles would capture enough neutrons to become strongly beta active; in a fatal case in the U.S. a beta burn was found in the gum resulting from radio-activity induced in a gold tooth filling. The greatest dose in a criticality accident would be from hard γ-radiation which would cause burns and severe blood changes. In following these and less serious exposures automatic blood counting machines were of great value. Unfortunately they still could not do a differential leucocyte count, though by using different diluents separate counts of red and white cells were possible.

The sodium–potassium ratio in the blood was altered by gross exposure. Instruments for measuring this ratio incorporated a flame photometer. Other diagnostic aids showed the occurrence of changes in the plasma proteins and, in males, a fall in sperm count. Prognosis was difficult in such cases, though negative findings had a great reassurance value.

INTERNAL RADIATION AND WHOLE BODY MONITORING

The discussion of internal radiation effects was oriented round the concept of the "standard man." Calculations of maximum permissible levels of radioactive substances in air and drinking water were based on his statistics. Air sampling was carried out through filter paper, surface contamination was assessed with a counter and ratemeter, and special probes were used for monitoring wounds or in other confined spaces. Great care was necessary in the case of suspected contamination by plutonium because its α-particles had a very short range, less than 1 cm in air, and could be absorbed in a very thin layer of water or blood.

Various types of whole body monitor had been constructed for measuring radiation emanated from a human being. Instruments were in existence using either scintillation counters or ion chambers. A development of the scintillation principle was the Loss Alamos counter. This had a large, double-walled cylinder into which the patient was slid. The cavity between the walls was filled with 140 gallons of an organic liquid phosphor, such as a solution of terpenyl or phenyl oxazone. The resulting light flashes were recorded by 108 photomultiplier tubes. This instrument enabled rapid measurements to be made of whole-body activity, though fir discrimination between energies would be difficult. None the instruments was satisfactory for elements like plutoniu emitting little or no gamma radiation. Weak γ-rays coul not be resolved against the natural background and the bod content of ^{40}K. ^{90}Sr, another long-lived isotope causin anxiety on medical grounds, had no gamma emission an betas of only 0·54 MeV, that is, one-third the strength of ^{40}K

The other method of searching for radioactivity in the bod was to check the excreta. Radon in the breath gave a index of radium, and plutonium and tritium could be detecte in very small quantities in urine, though the procedure wa complicated. Uranium was the easiest analysis to mak ultra-violet fluorescence of a prepared residue was compare with known standards by photofluorimetry.

For differentiating unknown α-ray emitters a remarkab α-spectrometer had been constructed. It contained sever hundred valves and operated on 100 channels, each of wh counted pulses in a very narrow energy band. A modif version dealt with β- and γ-radiation from mixed fissi products. High activity samples were put in a recordi γ-ray spectrograph and the resulting peaks were subsequen scanned for amplitude. This instrument eliminated the ne for preliminary chemical preparation. It would give quantitative analysis of mixed fission products in, for exampl a splash following an accident in the chemical separati plants.

Copies of the full proceedings are obtainable from th Scientific Secretary, British Occupational Hygiene Societ Medical Research Council Laboratories, Holly Hill, Ham stead, London, N.W.3.

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ORIGINAL CONTRIBUTIONS

A high-precision photoelectric polarimeter

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In this instrument, which has been designed primarily for standardization work on quartz control plates, the half-shade principle familiar in visual polarimeters is realized, in a slightly different form, by means of a revolving disk carrying segments of optically-active quartz. These cause the plane of polarization of the light incident on the analyser to alternate between two positions at a low audio-frequency; the setting position of the analyser is that in which the intensity of the emergent light, as indicated by means of a photomultiplier and a.c. amplifier, is unmodulated. The precision of setting is about ten times better than that of a visual instrument. For measuring specimens of small optical activity, use is made of the Faraday effect to balance out the rotation produced by the specimen, thus obviating the need for angular scale readings.

INTRODUCTION

larimeters and saccharimeters are widely used in the sugar lustry, and the calibration of the quartz control plates ich are used for checking these instruments is of con- erable commercial importance. In this country calibration entrusted to the National Physical Laboratory, and has herto been carried out by standard visual methods.

Since the precision of a single setting with a visual polari- ter is of the order of 0·004°, it would appear that the eed figure for accuracy of 0·008° could be easily reached. wever, the measurements are subject to a number of tematic errors, often no greater than the random errors observation, but needing separate study if the desired uracy is to be claimed with confidence.

Such investigations require much tedious work by skilled servers, and any improvement in the precision of measure- nt, such as might result from using photoelectric instead visual methods, would help enormously to confirm the uracy at present claimed, and also to satisfy the current nands for still greater accuracy. The following is an ount of the photoelectric polarimeter which was developed h these objects in view.

PHOTOELECTRIC POLARIMETER—GENERAL DESIGN PRINCIPLES

The half-shade principle used in visual polarimeters, whereby the analyser of the instrument is set to equalize the intensity of two beams polarized in slightly different directions, has analogies in many other branches of instrument design, and is essential to polarimetric work of any precision. In a visual polarimeter the two beams occupy different parts of the field of view and are compared simultaneously. In a photoelectric instrument, this method of comparison would require two photocells; it seems better that the comparison should be a sequential one, effected by means of a single photocell. The two beams could then follow the same optical path through the instrument, and systematic errors due to asymmetry would thereby be minimized.

A system of this kind would comprise a polarizer and analyser, and between them some device for switching the plane of polarization back and forth through a suitable half-shade angle. The setting position of the analyser would be that in which the intensity of the emergent light, as indicated by a photocell, remained constant. The switching of the plane of polarization could be done by hand and accompanied by spot measurements of photocell response,(1) but there is an obvious advantage in performing the switching automatically and continuously at a fixed frequency, preferably in the audio range or above. Any deviation of the analyser from the true setting position will then produce an a.c. signal; a.c. amplification may then be used to eliminate automatically the effects of zero-drift, or slow changes in overall sensitivity such as might be caused, for example, by variations of lamp intensity.

This arrangement is used in the instrument described here. The polarization-switching device (see Fig. 1) consists of a glass disk carrying segments of optically active quartz arranged so that, as the disk revolves, they pass in turn through the beam of light, and so rotate the plane of polarization back and forth. By using superimposed plates of right- and left-handed quartz of suitable thickness, the rotation, and hence the half-shade angle, may be set to have any desired value from zero upwards. The initial choice of half-shade angle may therefore be made purely from considerations of sensitivity, precision and accuracy, all of which are likely to be influenced by the half-shade angle to as great an extent as in a visual polarimeter. It is appropriate to discuss these considerations now, since the value set for the half-shade angle has a marked influence on the subsequent stages of design.

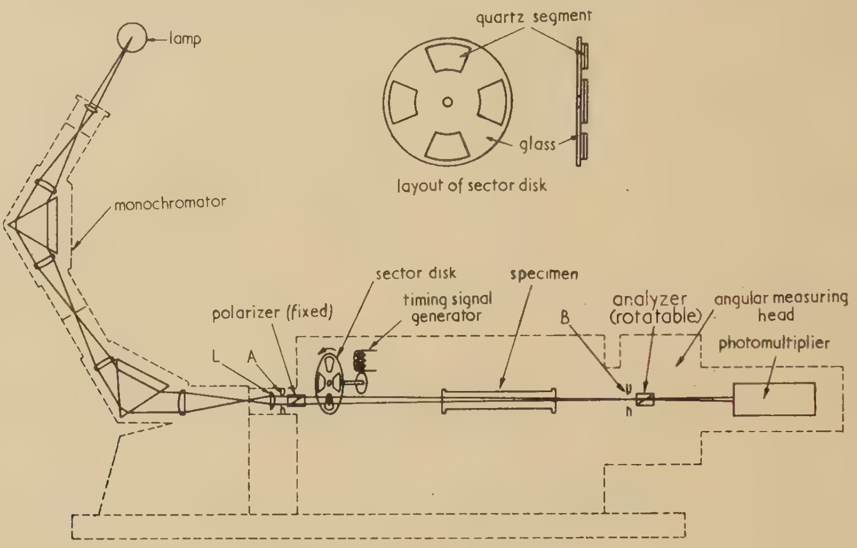

Fig. 1. Details of polarimeter

CHOICE OF HALF-SHADE ANGLE

If the analyser (Fig. 2) is set along OA at an angle ϕ with the crossed position, then the difference in the intensity of the light emerging from the analyser, for the two directions of polarization OP_1 and OP_2, is

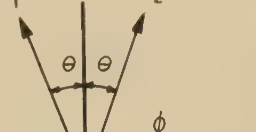

Fig. 2. Setting of analyser

$$\Delta I = I_0[\sin^2(\theta + \phi) - \sin^2(\theta - \phi)] = I_0 \sin 2\theta \sin 2\phi$$

where I_0 is the intensity of the light emerging from th polarizer and θ is the half-shade angle. The alternatin component of the photocell response will depend only on thi difference, and not on the mean level of intensity $I_m =$ $I_0 \sin^2 \theta$ so that the sensitivity of the system, regarded as th rate of change of this alternating component with angula setting error ϕ, is proportional to

$$d\Delta I/d\phi = 2I_0 \sin 2\theta$$

This result, which indicates maximum sensitivity fo $\theta = 45°$, contrasts with that which holds when, as in a visua instrument, the sensitivity of the detector depends on th mean level of intensity I_m. However, more important tha sensitivity is precision, which is determined, not by sensitivit alone, but by the relation between sensitivity and the noi generated in various parts of the system. If this is mai amplifier noise and independent of I_m, then indeed sensitivi and precision will be equivalent. However, if a phot multiplier is used as the detector, it is frequently possible t reduce amplifier noise well below the shot noise in the prima photocurrent, so that the precision will then be limited b shot noise and other types of noise which vary with I_m. I this case the half-shade angle may have an optimum valu considerably less than 45°.

For example, the shot-noise fluctuations in terms of ϕ ar proportional to $\sqrt{I_m}/(d\Delta I/d\phi) = \frac{1}{2} \sec \theta$ and are therefore minimum for $\theta = 0$. Of course if these were the on fluctuations it is unlikely that the small increase in precisio which is to be gained by reducing θ below 45° would b worth the accompanying loss in sensitivity. However, oth noise sources must be anticipated which, like shot nois operate through the medium of the light falling on the phot cell, but which vary in intensity, not as $\sqrt{I_m}$, but as I_m. Th will be true, for example, of noise produced by fluctuatio in lamp output or photomultiplier gain, or by any disturban of the light beam by mechanical vibration. Since noise of th type varies, in terms of ϕ, as $\sin^2 \theta/\sin 2\theta$, i.e. as $\tan \theta$, t advantage of a half-shade angle less than 45° may well b significant.

Similar considerations apply to the systematic errors whic limit the accuracy, as distinct from the precision, in t measurement of optical rotation. Most, if not all, suc errors can be expected to act through the medium of t ht beam, by favouring its transmission in one half or the ier of the polarization-switching cycle to an extent which ies with the rotation of the specimen. The errors may erefore be expected to vary, in terms of intensity, as I_m, d in terms of ϕ, as tan θ. The accuracy therefore improves h decreasing θ, a conclusion which is consistent with the t that since the setting position of the analyser is, as it were, cketed by OP_1 and OP_2 (Fig. 2), the total systematic or must be less than θ.

Thus both precision and accuracy will improve with creasing θ until amplifier noise begins to outweigh shot ise. If a photomultiplier is used, and the amount of light similar to that usually available in precise visual polari- try, then this stage will probably not be reached until θ ess than about 1°. However, the assumption $I_m = I_0 \sin^2 \theta$, which these conclusions are based, may be incorrect at ch a small angle, owing to the presence of unpolarized or iptically polarized light, caused by scattering or bire- ngence in some part of the optical train. It is known that visual polarimetry such effects are often responsible for ting a lower limit to the half-shade angle. It therefore emed desirable that the half-shade angle should not be less in the value of 2 or 3° which has been found acceptable in ual polarimeters, the more so since it was hoped that the ecision would approach the shot-noise limit, which varies ly slowly with θ. A value of 3° was therefore decided on.

DESCRIPTION OF POLARIMETER—OPTICAL AND MECHANICAL DETAILS

It is seen from Fig. 1 that the instrument is arranged so it the light passes in turn through the polarizer, the revolv- g disk, the specimen to be measured, and finally the alyser. As in a visual instrument, the polarizer is fixed, d settings are made by rotating the analyser, which is ached to a precision angular head readable directly to 001° and by estimation to 0·0001°. It would have been ssible, of course, to adopt the alternative arrangement of ed analyser and adjustable polarizer, but there appeared be no obvious reason for doing this. Both polarizer and alyser are high-quality calcite prisms of the Green type.

It has perhaps been implied that the revolving disk is signed so as to switch the plane of polarization back and rth symmetrically about the mean direction set by the larizer. A symmetrical action of this kind could quite sily be achieved by using alternate segments of right- and t-handed quartz, but is unnecessary in the particular plication for which the polarimeter is intended. It was erefore possible to economize in the manufacture of the k by omitting every other quartz segment (see Fig. 1), and ranging that the remainder, four in number, should each tate the plane of polarization in the same sense through ice the half-shade angle, i.e. 6°. Since the thickness of artz required for this rotation at 5461 Å is rather small, ch segment was made by cementing together two plates of ht- and left-handed quartz differing in thickness by the quired amount. The glass disk to which the segments are ached is worked to a slight curvature on its free face so it its optical transmission shall not be unduly influenced interference effects. The disk is belt-driven from a small otor at a speed of about 1000 rev/min, thus the frequency oscillation of the plane of polarization is about 70 c/s.

The revolving disk is subject to some stress, induced either chanically or by heat conducted from the motor, and erefore tends to exhibit slight birefringence, although with table design this is such as to be barely visible with crossed Nicols. The elliptical polarization caused by the birefringence is insufficient to affect the sensitivity of the polarimeter appreciably, and the slight rotation of the mean plane of polarization, which is another effect of the birefringence, is merely equivalent to a shift of zero. In any case, both effects can be substantially eliminated by suitably orienting the polarizer. It is to be noted, however, that if the revolving disk were situated next to the analyser instead of the polarizer, as at first sight seems possible, then the birefringence could cause quite large systematic errors, for the rotation which it produces, depending as it does on the angle between the axes of birefringence and the original plane of polarization, would vary with the optical rotation of the specimen being measured.

The geometry of the optical system is determined by two requirements, first that the beam of light should be slightly smaller in cross-section than the aperture of a normal quartz control plate, and secondly that the angular spread of the rays in the beam should not be so great as to influence materially the optical rotation which is to be measured. These requirements are satisfied by means of the circular diaphragms *A* and *B*, and the lens *L* which images on to *B* the exit aperture of the monochromator. The diaphragms which thus define the light-gathering power of the optics are each 6 mm in diameter, and are separated by a distance of 570 mm.

A turret mechanism is provided for holding the quartz control plates, or other specimens undergoing measurement, and inserting them in the beam as required. Since the turret is capable of holding as many as eight specimens at once, little time need be lost in reaching stable temperature conditions.

The monochromator required for isolating the 5461 Å radiation from the mercury lamp has been constructed as an integral part of the instrument, in order to secure good rigidity and so minimize the effect of vibration in the beam of light passing through the instrument. For the most accurate work, absolutely pure radiation is required, and the monochromator is therefore a double instrument, of the Van Cittert type with opposed dispersion. The 60° prisms of DEDF glass (Chance type 748 278) are 1 in. high, and have a base length of 3 in, sufficient to give a waveband with a total width of 100 Å. Lenses working at $f/6 \cdot 5$ are used for collimation and focusing, and circular apertures replace the normal monochromator slit, in order to cut down the amount of light to that actually used by the polarimeter and so reduce stray light. The somewhat unusual disposition of the monochromator in a vertical plane was chosen partly to save space, and partly to ensure that the structure should be as rigid as possible.

DESCRIPTION OF POLARIMETER—ELECTRICAL DETAILS

The photomultiplier is an 11-stage E.M.I. tube, type 6094B, with a transparent caesium-antimony cathode 1 cm in diameter. This photomultiplier has the advantage that its cathode is flat and therefore insensitive to the polarization of the incident light. It was estimated that, with a half-shade angle of 3°, the mean illumination of the cathode with the analyser crossed would be such as produce a primary photocurrent of the order of 10^{-12} A. The amplification factor of the tube, which at full operating voltage is about 10^7, is therefore more than sufficient, since best performance is obtained with a collector current not much greater than 1 μA.

The electrical equipment which follows the photomultiplier (see Fig. 3) is required to amplify and rectify the 70 c/s component of the collector current. In view of the expected precision of about 1″ in the setting position of the analyser, it was decided that full scale deflection on the output indicating meter should correspond to about 0·02°. The signal amplitude i_s available from the photomultiplier with an angular displacement of this order may be got from the relation $i_s = i_{DC}\frac{8}{\pi}\frac{\theta}{\pi}$, where i_{DC} is the standing current in the photomultiplier output. Putting $i_{DC} = 1\ \mu$A and $\theta = 0{\cdot}02°$ gives $i_s = 10^{-8}$ A.

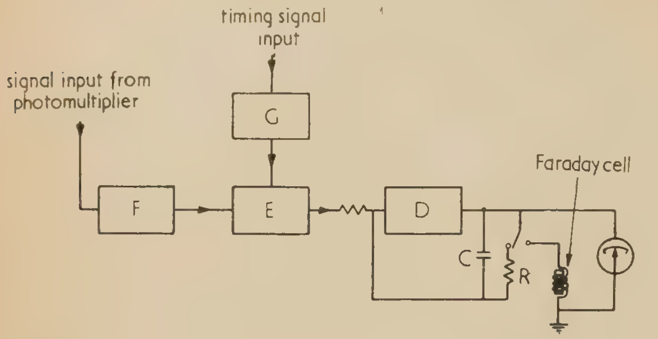

Fig. 3. Electrical layout following the photomultiplier

D, d.c. amplifier; *E*, phase sensitive detector; *F*, a.c. amplifier; *G*, timing signal amplifier.

It was decided that the rectifier should be phase-sensitive, so that the output meter might indicate the sign as well as the magnitude of the angular setting error. This would facilitate setting of the analyser by hand, and would be essential should any form of automatic setting be desired. Furthermore, this type of rectification can discriminate against a signal in quadrature with the true signal, such as might be caused, for example, by the edges of the quartz segments interrupting the light beam. Such a signal could well reduce the sensitivity and ultimate precision enormously if straight detection were used. Finally, only with phase-sensitive rectification is it possible to realize the full advantage, in signal-to-noise ratio, of the potentially narrow bandwidth associated with the response time of the output indicating meter.

The phase-sensitive detector requires for its control a timing signal synchronized with the rotation of the sector disk. This is generated by means of a magnetic variable-reluctance device, embodying a Keramot disk mounted on the same shaft as the sector disk, and carrying at equal intervals round its periphery four soft iron studs. As the disk rotates, these plugs pass in turn through a gap in a permanently magnetized magnetic circuit, and induce the required signal in a coil linked with the magnetic circuit.

The d.c. amplifier which follows the rectifier gives sufficient current to operate a robust milliammeter, and also enables the response-time of the meter to be easily controlled by means of variable a.c. feedback. The amplifier input can, when required, be switched so that the output meter displays the mean d.c. current in the photomultiplier output.

The d.c. amplifier uses a balanced valve circuit, but is nevertheless subject to a certain amount of zero drift. If this drift is to be reasonably small in terms of angle, the a.c. amplifier must have adequate gain; at the same time, however, the detector must not be overloaded with noise. It was therefore necessary to reduce the noise at the detector by making the a.c. amplifier somewhat selective, with a bandwidth of about 100 c/s. Since a bandwidth of this order implies rather a rapid change of phase with frequency, th timing-signal amplifier was designed to have a simila phase-*ν*-frequency characteristic, so that possible smal changes in motor-speed, and hence frequency, should no alter the relative phase of signal and timing signal.

In order to protect the photomultiplier from the high illumination which results when the analyser and polarizer are parallel, the e.h.t. stabilized power supply for the photomultiplier is designed to act, at any rate at zero and sub-audio frequencies, as a constant-current generator, with effectively a very high internal resistance. At audio frequencies, where the stabilizer has the important function of suppressing hum the circuit is designed to stabilize voltage rather than current since a higher stabilization factor may be obtained in thi way. The output of the stabilized supply may be varied continuously up to a maximum value of 0·1 mA (corresponding to 150 V across each photomultiplier stage). Thi variation provides all that is required in the way of a gain control for the system.

OPERATION AND PERFORMANCE OF INSTRUMEN

When the instrument is first operated, it is usually convenient to find the approximate crossed position of th analyser by observing the d.c. photomultiplier current, wi the gain turned down to a suitably low level. The gain i then increased until the d.c. current is about 1 μA; by thi means the gain is set to the level at which the amplifier an detector work most efficiently. The output meter is th switched over to normal operation, the time-constant of t indicating system adjusted to suit the observer, and t analyser set to bring the meter to zero.

The precision of the instrument was investigated simply b observing the fluctuations in the reading of the output mete In typical conditions these were found to have an r.m.s value in terms of angle of about 2″. The significance o this result can be assessed more easily with the aid of th following summary of the principal features of the system.

Lamp:	Cooper–Hewitt Hg arc, fed wit d.c.
"Light-grasp" of optics:	Two 6 mm dia apertures 570 mm apart.
Radiation available: (5461 Å)	Equivalent, on emerging fro polarizer, to a primary photo current of 2·3 10^{-9} A
Half-shade angle:	3°
Photomultiplier gain:	$\sim 10^5$
Overall sensitivity:	Full-scale deflexion of outpu meter for analyser rotation o 0·02°
Overall bandwidth:	0·11 c/s (as set by a time-constan for the indicating system o 2·2 s)
Measured fluctuations:	R.M.S. value ~2″ (as above)
Fluctuations due to shot-noise:	Calculated value for the abov bandwidth 0·46″

The performance represented by the above figures fall short of the theoretical limit set by shot noise, but not, it i considered, to an extent which requires detailed investigation It was, however, noted that the fluctuations could be reduce to about shot-noise level by stopping the rotating disk; thi suggested that the excess noise was not due to the lamp o photomultiplier, but was probably caused by vibration. T determine the accuracy of the instrument in the measuremen of optical rotation is obviously more difficult than to determine the precision; in fact it requires a protracted investigatio ler conditions of close temperature control. This investi-ion is not yet complete, but results to date indicate that systematic error probably does not exceed about 4″.

The method of using the instrument described above, in ich the analyser is set to give a null reading on the output ter, is quite satisfactory for most purposes. A combined l and deflexion method would have some advantages, and uld be quite practicable but for the fact that the overall sitivity, depending as it does on lamp brightness and otomultiplier gain, tends to be rather variable. This iculty could be overcome if there were some more con-ient method of calibrating the meter deflexion in terms of gle than the direct but time-consuming method of rotating analyser.

Dne alternative method of producing a small and easily asurable rotation for calibration purposes is provided by Faraday effect, whereby a magnetic field directed along ight-ray passing through a medium such as glass, rotates plane of polarization through an angle proportional to magnetic field-strength. A "Faraday cell" embodying s principle was therefore constructed, and mounted in the arimeter between the rotating disk and the specimen der. It consisted essentially of a rod of Chance SDEDF ss No. 030, 181, 1 cm in diameter and 5 cm long, wound h 38 000 turns of 42 s.w.g. enamelled copper wire (coil istance about 7 kΩ). With this cell, an optical rotation of 02°, which is roughly the angle required for full-scale lexion of the output meter under normal conditions of eration, was produced with a coil current of a ¼ mA. The ial calibration of the cell against the angular scale could, course, be carried out very easily to the required accuracy using a considerably higher current than this.

t was soon realized that this Faraday cell offered a means merely of measuring the overall sensitivity, but of bilizing it at a definite value. This could be done simply connecting it to the output of the d.c. amplifier (Fig. 3), reby forming a closed-loop negative-feedback system. en, provided the loop gain is sufficient, the cell-current will automatically adjusted so as to annul any rotation of the ne of polarization, and the magnitude of the cell-current l give a measure of rotation with an accuracy dependent y on the stability of the cell and the accuracy of its initial ibration.

This system was tried out with circuit values adjusted to give full-scale deflexion of the output meter for an angular rotation of 0·05°. It is seen from Fig. 3 that the switch S which brings the system into operation by connecting up the Faraday cell also disconnects the internal feedback resistance R. This serves to increase the overall loop gain to a sufficient value (about 50). It was possible to arrange that the time-constant of the indicating meter, which with straight operation is determined by R and C, remained unaltered. The system worked very satisfactorily, with an overall gain-stability consistent with the above value for loop-gain, and a signal-to-noise ratio similar to that for straight operation.

CONCLUSIONS

The polarimeter has an accuracy at least one order of magnitude better than that of a visual instrument, and adequately fulfils the purpose for which it was developed. So far as other possible applications of this type of instrument are concerned, it must be admitted that the revolving quartz-segment disk on which the instrument is based is more suitable for a laboratory instrument than one intended for industrial use, particularly since it now appears possible to perform its functions rather more simply by means of the Faraday effect.(2) This is probably true, however, only where a small half-shadow angle is required, and then only over a limited range of wavelengths. There are many applications, particularly in the growing field of ultra-violet polarimetry, where the optimum half-shadow angle is greater than can readily be got by this means, and here the quartz-segment disk may prove extremely useful.

ACKNOWLEDGEMENTS

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Some improvements in the operation of the optical diffractometer

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A systematic method of adjusting the components to bring their optical axes into coincidence is described. This is followed by an account of a theoretical study of the variation of partial coherence which leads to the formulation of a set of practical rules for choosing the correct size of pinhole for a particular problem. Some minor improvements in the design of the diffractometer and in the photographic techniques employed are also described.

1. INTRODUCTION

study of optical diffraction methods in relation to X-ray raction problems was started in this laboratory in 1949. ce that time several papers(1–4) have appeared on the ign of equipment and on applications. At first, most of effort was concentrated on the latter and a number of ical problems were temporarily put on one side; they were sidered to be of rather academic interest compared with main problem of developing techniques for crystal-icture determination. It has now been possible to take up the study of some of these optical problems and—as might have been foreseen—the results have turned out to be of considerable practical importance and have a direct bearing on the adjustment and use of the instrument. The present paper consists mainly of an account of these studies and of their practical implications for users of the equipment.

It must be emphasized that all the modifications in design and technique to be described are not essential for all users; a great deal of useful work, particularly on the simpler organic structures, can be done with quite crude apparatus. It is essential, however, in any piece of research work, to know the precise limitations of one's apparatus, even though it may not be necessary always to work near the limit. It is with this idea in mind that the present paper has been written. A companion paper on the accuracy and limits of validity of the applications in crystal-structure determination is in course of preparation and will be published elsewhere.

In the optical diffractometer, as in all optical instruments, the purpose of the optical components is to control the relative phases of the various beams of light involved; in an ideal diffractometer a perfectly parallel beam, of constant amplitude and phase across the whole aperture of the system, should impinge on the mask and the phase changes introduced by the lower lens between the mask and the focal plane must be identical for all beams parallel to a given direction. These conditions are remarkably difficult to achieve in practice, as is demonstrated by the frequency with which reports are received that non-centrosymmetrical patterns are obtained with optical diffractometers in apparent defiance of Friedel's law. Friedel's law, however, only holds for an object which scatters *in phase* and, although a mask of holes always scatters in phase, a departure from the ideal conditions just described may be equivalent to the use of an object which does not scatter in phase, and therefore does not obey Friedel's law.

There are four main causes of departure from ideal operation. First, there may be defects in the lenses themselves; it is important to have lenses of the best quality that one can afford and that they should be clean. Imperfections in blooming, patches of grease, or condensation will all ruin their performance. (It should perhaps be mentioned that the requirements for a diffractometer are in many ways more stringent than those for other optical systems; in projectors, telescopes, and other image-forming devices beams from every part of the lens reach every point in the image, and minute imperfections—bubbles, striae, grease spots, etc.—forming only a tiny fraction of the total aperture have little effect. In the diffractometer, however, one small bubble can change the whole pattern if it happens to coincide with a hole in the mask. It is thus essential that a lens with a good detailed performance over its whole aperture is chosen; good overall performance is not necessarily a sufficient criterion.)

Even poor lenses, however, may have their performance made much worse by incorrect adjustment and the second cause of departure from ideal conditions is faulty alinement of the system. Section 2 of this paper deals with a systematic method of alinement and it is strongly recommended that all users of diffractometers—whether equipped with high or low quality lenses—should adopt this or some comparable procedure when setting up their apparatus.

Thirdly, any irregularity in phase of the light emerging from the pinhole and impinging on the collimator lens may have a very large effect on the performance. A theoretical study of the so-called "coherence" properties of the illuminating system has therefore been made and in Section 3 an account is given of this study, together with a set of working rules that can be used to determine the best conditions for a particular instrument and a particular problem.

The fourth source of departure from ideal conditions is incorrect focusing. This is not difficult to avoid with small masks but becomes more difficult as one proceeds to larger ones. A simple modification to the instrument that partially solves the problem is described in Section 4, but work is still in progress on this problem and it is hoped to give a fuller account of its solution later. Also included in Section 4 is an account of one or two other minor changes in design that are recommended. In Section 5 some photographi techniques that have been found useful are discussed.

2. ALINEMENT OF THE DIFFRACTOMETER

Introduction. The basis of the procedure to be describe is undoubtedly well known to optical experts, but full detail are given because it is thought that it may not be familiar t many users of optical diffractometers.

The object of the alinement procedure is to ensure that a the components of the system have a common optical axis The axis of the system is already defined approximately b the structural design and it is important, first of all, to adjus all the mounts for the components so that their centres li approximately along this axis; as the alinement proceeds the changes required are then likely to be within the rang of the adjustments provided. (All components must b provided with lateral centring adjustments and the mai lenses must, in addition, have provision for angular adjustment.) It also saves time if the pinhole is placed approximately in the back focal plane of the collimating lens befor the procedure commences. When these preliminary adjustments have been made, all the optical components except th lamp, S_0 (Fig. 1), the pinhole S_1 and the mirror M shou be removed.

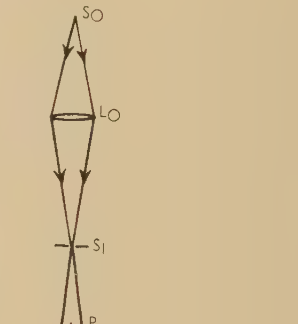
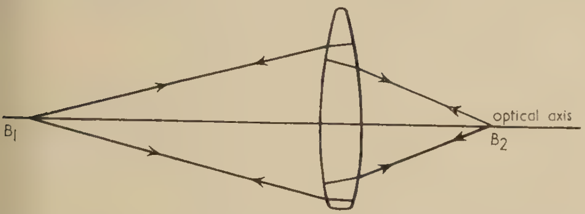


Fig. 1. The optical system of the diffractometer

Definition of the optical axis. The optical axis is taken, a first, to be the line joining the pinhole to the centre of th upper lens mount. This ensures that the axis is as near a possible to the geometrical axis. It must then be define rimentally by the following procedure. A 1 mm pinhole aced at S_1 and a disk of white card with its centre point rly marked is placed in the mount for L_1. The lamp is adjusted until the pinhole image of one of the two ht spots in the arc coincides with the centre of the disk. Section 4.) A pinhead is now placed at P, about 18 in. w S_1 and adjusted so that the centre of its shadow also cides with the centre of the disk. The cathode spot, the ole, the pinhead and the centre of the disk now all lie in raight line which coincides with the geometrical axis of instrument and which is now taken to be the optical axis. white disk can be removed and the intersection of the cal axis with the plane of any component of the system now be found by observing the position of the centre of shadow of the pinhead on a piece of paper placed in that e. The lamp, pinhole and pin should not now be moved l the alinement of the lenses L_1 and L_2 is completed.

linement of main lenses. A lens is manufactured by ting two spherical surfaces on a glass blank. The axis of lens is the line which is a common radius for the two aces and this usually does not pass through the geo-rical centre of the lens disk. In mounting the lens, the ufacturer "edges" the disk so that this defect is remedied. technique by which this is done may be satisfactory for st purposes, but, in the authors' experience, it is not rate enough for the optical diffractometer and it is, efore, necessary to define the axis *optically* and not by rence to the geometry of the lens. The most satisfactory hod is to make use of the "Boys" points.(5) A bright t source can be adjusted to be coincident with its image ned by reflexion at the back surface of the lens (B_1, Fig. 2).



ig. 2. Formation of the "Boys" points. The lens has urposely been drawn so that its optical axis does not pass through the geometrical centre of the rim.

imilar point can be found on the opposite side of the lens Fig. 2). The line B_1B_2 must then be the axis of the lens. nodification of this principle is used for the alinement. single point source is placed some distance from the lens n Fig. 3), several subsidiary images (I_1, I_2, etc.) will be ned by single and multiple reflexions, in addition to the n refracted image I. If the source and any two of these ges can be made to lie in a straight line, then this must he axis of the lens. Thus, since the pinhole (S_1, Fig. 1) ne diffractometer is already on the axis, if a lens can be sted so that two subsidiary images also lie on the axis dy defined, then the axis of the lens is coincident with defined axis of the instrument.

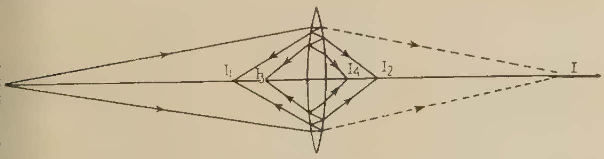


Fig. 3. Formation of the "subsidiary images"

oth angular and lateral adjustments are required. A consideration of Fig. 3 will show that the lateral position of I_1 will be critically dependent on the angle of incidence on the lens of rays from the source. On the other hand, since the formation of I_2 involves reflexion at both surfaces of the lens, displacements due to change of angle of incidence will tend to cancel each other. The general principle emerges that any subsidiary image formed by an odd number of reflexions will be particularly sensitive to angular adjustment and a subsidiary image formed by an even number of reflexions will be comparatively insensitive to angular adjustment. It is thus possible to separate partially the two variables and, by making alternate lateral and angular adjustments, and always using the appropriate subsidiary image, to approach the correct alinement quite rapidly.

The procedure is to place the lower lens (L_2, Fig. 1) in position first. In order to make the subsidiary images bright enough to be seen, the condenser is placed in position at L_0 (Fig. 1) and adjusted to form an image of the cathode spot on S_1. The lamp and pinhole must not, of course, be moved. The two brightest subsidiary reflexions are then located (if multi-component lenses are used there will be many more subsidiary reflexions; Fig. 4 shows the approximate positions actually found with one particular lens). A convenient way of finding the reflexions above the lens is to use a piece of fine wire gauze as a screen. This permits a large amount of light to pass through to the lens and at the same time forms a good screen on which to receive a returned image. The shadow of the pinhead can also be seen on the gauze and it is a simple matter to adjust the lens until the subsidiary reflexion lies in the centre of the shadow of the pinhead, and hence on the axis. As already mentioned, the procedure is repeated alternately for angular and lateral adjustment until the two reflexions both lie on the axis.

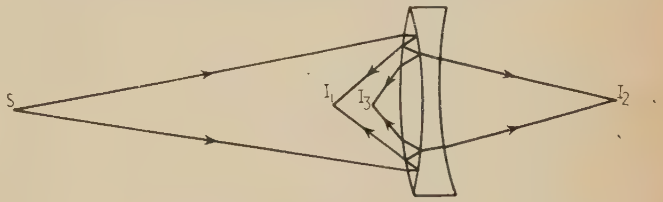


Fig. 4. Positions of subsidiary images for a typical lens

Lens L_1 is then placed in position and it will be found that an additional set of subsidiary reflexions involving both lenses will be formed. However, it is a simple matter to find by experiment which reflexion is most sensitive to angular adjustment of L_1 and which is most sensitive to lateral adjustment. The same procedure as before may then be followed.

The axes of the two lenses are now coincident with each other and with the axis already defined.

Fine adjustment of the pinhole position. It is now necessary to adjust the pinhole to be accurately in the back focal plane of the upper lens. In doing this the pinhole may be moved laterally, but if the pinhead and the lenses remain unmoved it is quite simple to put the pinhole back on the axis by observing the relative positions of the shadow of the pinhead and one of the subsidiary reflexions.

The small accessory shown in section in Fig. 5 is found

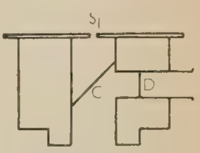


Fig. 5. Accessory used for placing the pinhole in the back focal plane of lens L_1 (Fig. 1)

most useful for the adjustment of the pinhole. A microscope cover slip C is mounted at 45° inside the pinhole mount and a screen D is placed in a tube fitted to the side of the mount so that the image of the ground surface of the screen in C is coincident with the plane of the pinhole.

A good mirror (the mirror M, taken out of its mount, is often used) is now placed on a support between the lenses so that the light reflected from it forms a returned image at the pinhole. Some of the light is reflected by C to D and the image formed there will correspond to that formed at the pinhole. The pinhole mount may then be raised and lowered until the image on D is sharp. It may help if a hair is placed across the pinhole during this adjustment. The pinhole must then be re-adjusted if necessary to be on the axis of the system as described at the beginning of this section. The mirror between the lenses should now be removed.

Adjustment of the mirror and camera table. The tilt of the mirror M (Fig. 1) is now adjusted until the shadow of the pinhead falls in the centre of the hole in the camera table. It is, of course, important also that the camera table—that is, the plane on to which the film is clamped during photography—should be normal to the beam from M. This is best achieved by placing a front-silvered mirror face down on the table. A returned shadow of the pinhead is then formed at the mirror—a piece of fine gauze may be used to view the shadow without interrupting the light beam—and by tilting the camera table the centres of the incident and returned shadows may be made to coincide.

If a microscope is used, it must also have its axis collinear with the image of the optical axis in M. This can be achieved by observing the many subsidiary reflexions from the various components of the microscope objective which form a set of circles, or ellipses, on the camera table. When the axis of the microscope is correctly adjusted the subsidiary reflexions are all circular and concentric (if the objective is properly assembled with all its elements on a common axis).

Preparation for use. The pinhead should now be removed and the pinhole accessory (Fig. 5) replaced by a standard pinhole, say, 10 μ in diameter. (All pinholes and the accessory are interchangeable and so constructed that, once the mount has been centred for the accessory, it is centred for all the pinholes.) A filter is now placed in position and the instrument is ready for use.

It is important to notice that if one component is accidentally moved after alinement is complete, it can be put back by observing the position of the image of the pinhole. If, however, more than one component is moved, the instrument must be completely re-alined.

3. COHERENCE PROPERTIES OF THE ILLUMINATING SYSTEM

Introduction. In the past, certain assumptions have been made, implicitly or explicitly, about the illumination of the diffracting object in an optical diffractometer. These assumptions are:

(*a*) that the part of the instrument above the pinhole is not important, provided that an image of the bright cathode spot of the arc is formed on the pinhole;

(*b*) that a pinhole diameter of 15–30 μ is suitable for most purposes;

(*c*) that, with the above pinholes, most diffracting objects are coherently illuminated.

In the following discussion, these assumptions will be investigated and shown either to be incorrect or to require considerable modification.

The basic idea of coherent and incoherent sources in inte ference experiments is fairly familiar, but the intermediat condition between these two extremes—known as parti coherence—is not so widely understood. It is best introduce by reference to the Michelson stellar interferometer.(6) I this instrument, two slits are placed in front of the objecti of a telescope and form fringes across the image of a star i the back focal plane. By varying the separation of the slit the contrast between the bright and dark parts of the fring system can be varied and, for certain spacings, the fring system may disappear altogether. Michelson related th variation to the diameter of the star, or to the separation o a star doublet. It is clear that, if the fringes have maximu contrast the two slits are being illuminated coherently, and the fringes disappear altogether the illumination of the sli must be incoherent. The intermediate degrees of contrast— or visibility as Michelson called it—must therefore correspon to varying degrees of partial coherence. Thus Michelson experiment really consisted of an investigation of the chang in coherence of the illumination as the two slits were move apart and this in turn was related to the star diameter.

The optical diffractometer presents a close parallel; th pinhole source is at the focus of the upper lens and conse quently, as far as the lower lens and the rest of the system concerned, is equivalent to a source at infinity—analogous t the star in Michelson's work. The lower lens corresponds t the telescope objective and two slits placed between the lense will give a fringe system at F (Fig. 1). The visibility of th fringe system ought then to be related to the degree o coherence between the two slits. We thus have a method o investigating the coherence properties of the illumination.

Michelson measured the contrast or visibility in terms o a function defined as

$$V = (I_{max} - I_{min})/(I_{max} + I_{min}) \qquad ($$

and known as the visibility function, where I_{max} is the intensi of the central maximum and I_{min} that of the first minimum o the fringe system. This function is the modulus of th "degree of coherence." A degree of coherence of unity th corresponds to maximum visibility of fringes and complet coherence; a degree of coherence of zero corresponds t invisible fringes and complete incoherence. A numeric meaning can thus be attached to the conditions between th two extremes in terms of the visibility of fringes produced.

Theoretical treatment. Before the coherence distributio across the field can be studied it is necessary to consider th coherence across the pinhole itself. The pinhole has a fini diameter and is illuminated by an optical system forming a image of the source which certainly does not constitute coherent source as a whole. This factor turns out to be ver much more important than was originally thought. B varying the constants of the condenser and the distanc involved it is possible to produce any degree of coheren from zero to unity. Unfortunately the theoretical treatme for the coherence produced in the plane of the mask from partially coherent source is extremely difficult; only the tw extreme conditions will be treated here. In order to obta coherent illumination the diameter of the pinhole must b small compared with the diameter of the Airy disk,(7) i.e. th central maximum of the diffraction pattern formed by th condenser lens at the pinhole. This condition is usual expressed

$$\left(\frac{\text{diameter of pinhole}}{\text{diameter of Airy disk}}\right)^2 = \left(\frac{d_p}{d_A}\right)^2 \ll 1 \qquad ($$

'or incoherent illumination the reverse is true, i.e.

$$(d_p/d_A)^2 \gg 1 \quad (3)$$

f the condition expressed in equation (2) is obtained, then illumination over the mask is coherent in the area of the y disk formed over the mask. It will be shown later that condition is not really practicable.

Vhen the pinhole is incoherently illuminated the coherence tribution over the mask is not quite as straightforward may be calculated.

t has been shown by Zernike(8) and later by Hopkins(9) t γ_{12}, the degree of coherence between two points, is en by

$$\gamma_{12} = 2J_1(v)/v \quad (4)$$

ere v is a function of the distance apart of the two points J_1 is a Bessel function of the first kind. (Hopkins' work es the degree of coherence between the points to be

$$\gamma_{12} = [2J_1(v)/v] \exp [ikh^2/2r] \quad (5)$$

as we are only interested in intensities the degree of ierence may be defined by equation (4), since the exponential equation (5) only alters the phase.)

An experiment on the lines of the Michelson stellar interometer has been successfully carried out to verify qualiively the form of the function γ_{12} by Thompson and lf(10) using a mask containing two holes of variable distance irt. The fringe system resulting was investigated photophically. (A similar experiment has been carried out by cer(11) using slits; this has not a direct application to the ical diffractometer which employs circular symmetry.) n equation (4) the variable v has the form

$$v = (2\pi/\lambda)Nh \sin \alpha \quad (6)$$

ere λ is the wavelength used, h the distance between the points, α is the angle subtended by the pinhole at the tre of the lens L_1 and N is the refractive index and is here ial to unity.

'or $v = 1$, $\gamma_{12} = 0{\cdot}88$ and this is regarded in the literature a reasonable approximation to coherent illumination. ien $v = 1$, equation (4) becomes:

$$h_c = \lambda/2\pi \sin \alpha \quad (7)$$

ere h_c is the distance between two points which would both in a coherent beam. It will be noted that h_c has the allest possible value when $\sin \alpha = 1$, i.e. $h_c = \lambda/2\pi$; thus re is always some coherent illumination from an incoherent rce.

f v is taken equal to unity then there are two factors which ct the diameter of the coherent beam; they are the size he pinhole and the wavelength of the incident illumination. latter has very little effect as may be seen from Fig. 6. only other variable then is the diameter of the pinhole. effect of changing the diameter of the pinhole may be n from Fig. 7.

As the value of v changes in equation (4), or as we alter the ance between our two points on the mask, so the degree coherence γ_{12} changes. If the degree of coherence is tted against h then a curve of the type shown in Fig. 8 btained.

The fact that γ_{12} takes on a negative value means that there phase change of π, i.e. the fringe system is reversed. We primarily interested in the magnitude of γ_{12}; its modulus y be designated g_{12} which is the same as the Michelson visibility function V. The graph of g_{12} against h is given in Fig. 9.

Two points with separation AB, AC, AD, etc., will be incoherently illuminated with respect to each other. Furthermore, A and any point in the region of B will have a very

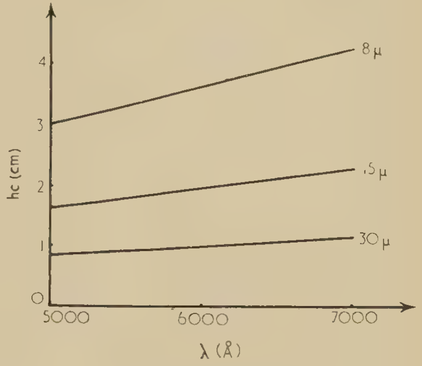


Fig. 6. Variation with wavelength of the diameter of the coherent beam

($\gamma = 0{\cdot}88$.)

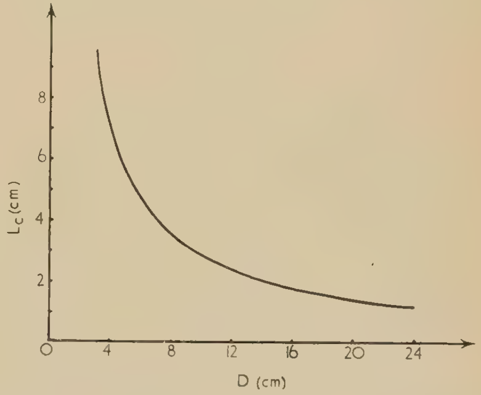


Fig. 7. Variation with pinhole diameter of the diameter of the coherent beam

($\gamma = 0{\cdot}88$ for $\lambda = 5790$ Å.)

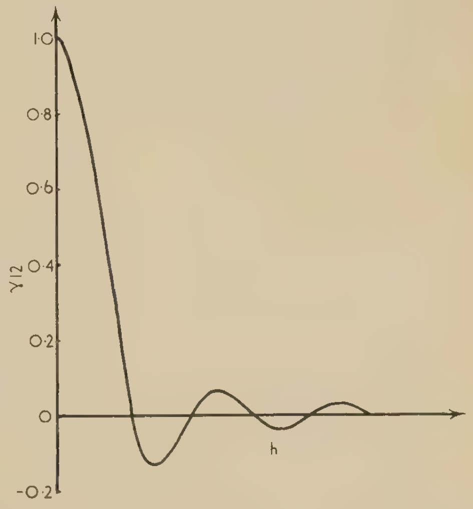


Fig. 8. The degree of coherence (γ_{12}) as a function of the separation of two points

small value of degree of coherence, i.e. the visibility of the fringes will be poor.

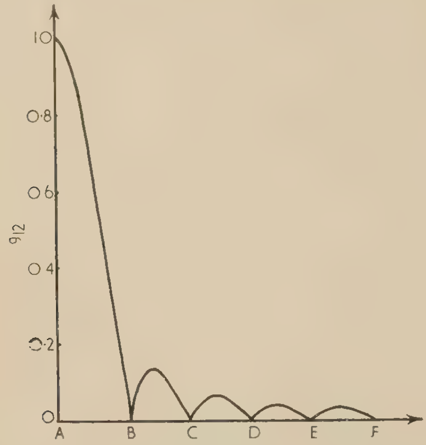


Fig. 9. The modulus of the degree of coherence (g_{12}) as a function of the separation of two points

In Table 1 the value of h is given for the distances AB, AC and AD for various diameters of pinhole.

Table 1. *Magnitudes of AB, AC and AD in Fig. 9 for various pinhole diameters*

Focal length = 152 cm

Diameter of pinhole (μ)	*AB* (*cm*)	*AC* (*cm*)	*AD* (*cm*)
110	1·08	1·80	2·5
56	1·9	3·5	4·9
30	3·95	6·6	9·8
15	8	13	

Since the diameters of the lenses are approximately 11 cm, then the distance AB becomes important, even with pinholes of diameter less than 30 μ, if the full diameter of the lens is to be used.

Practical applications and implications. Certain modifications to the diffractometer are required if use is to be made of the foregoing results. First, since the theory has been worked out only for either completely coherent or completely incoherent illumination at the pinhole, the illumination must be made to conform to one or the other of these conditions. Let us consider how these conditions may be achieved. The ratios given by equations (2) and (3) may be determined for any pinhole by calculating the diameter of the Airy disk.

Diameter of Airy disk

$$d_A = 1{\cdot}22 l\lambda/d \qquad (8)$$

where l is the distance of the condenser lens to the pinhole, d the diameter of the condenser and λ the wavelength of light used.

It is a reasonable approximation to re-write equations (2) and (3) in the following form:

$$\text{coherence } (d_p/d_A)^2 = 0{\cdot}01, \text{ i.e. } d_p/d_A = 0{\cdot}1 \qquad (9)$$

$$\text{incoherence } (d_p/d_A)^2 = 100, \text{ i.e. } d_p/d_A = 10 \qquad (10)$$

Then, for wavelength $\lambda = 5790$ Å, the ratios l/d in equation (8) may be determined. These ratios are given in Table 2 for two typical pinholes.

Table 2. *Relationship between pinhole diameter and the rat l/d of equation* (8) *for coherent and incoherent illumination*

Pinhole diameter (μ)	*Value of l/d for:* coherence	*incoherence*
30	426	4·25
10	141	1·41

If l has a value of 50 cm then the values of d become a shown in Table 3.

Table 3. *Relationships between pinhole diameter, condense diameter and coherence conditions for a fixed condense pinhole distance of* 50 *cm*

Pinhole diameter (μ)	*Value of d for:* *coherence* (*cm*)	*incoherence* (*cm*)
30	0·117	11·7
10	0·35	35·1

From Table 3 it can be seen that it is not practicable t obtain coherent illumination, since the condenser lens woul have to be stopped down to such a small diameter that the intensity of illumination over the pinhole would serious suffer. Thus it is advisable to use incoherent illumination of the pinhole. In practice, a condenser of fairly large diame is used and the value of l adjusted to suit this diameter. this condition is achieved for the smaller sizes of pinho then it must, of necessity, apply for the larger ones.

Let us now proceed assuming that we have arranged h conditions for incoherent illumination of the pinhole. Th coherence over the mask may now be investigated. It important to realize, at this stage, that from an incoher source coherent illumination can be obtained.

Depending upon the size of the punched area of the ma so a suitable pinhole must be chosen. It is possible, howeve to work in a region with γ_{12} rather less than 0·88 and st obtain good results. The limit, if good pictures are to b obtained, is $\gamma_{12} \sim 0{\cdot}5$. In Table 4 the values of $h_{0{\cdot}5}$ a given for various diameters of pinhole. It is useful if ri are drawn on a piece of transparent material correspondin to the diameters given in Table 4. If each ring is labelle with its pinhole diameter then, by placing a mask behind i the maximum diameter of pinhole may be chosen directly.

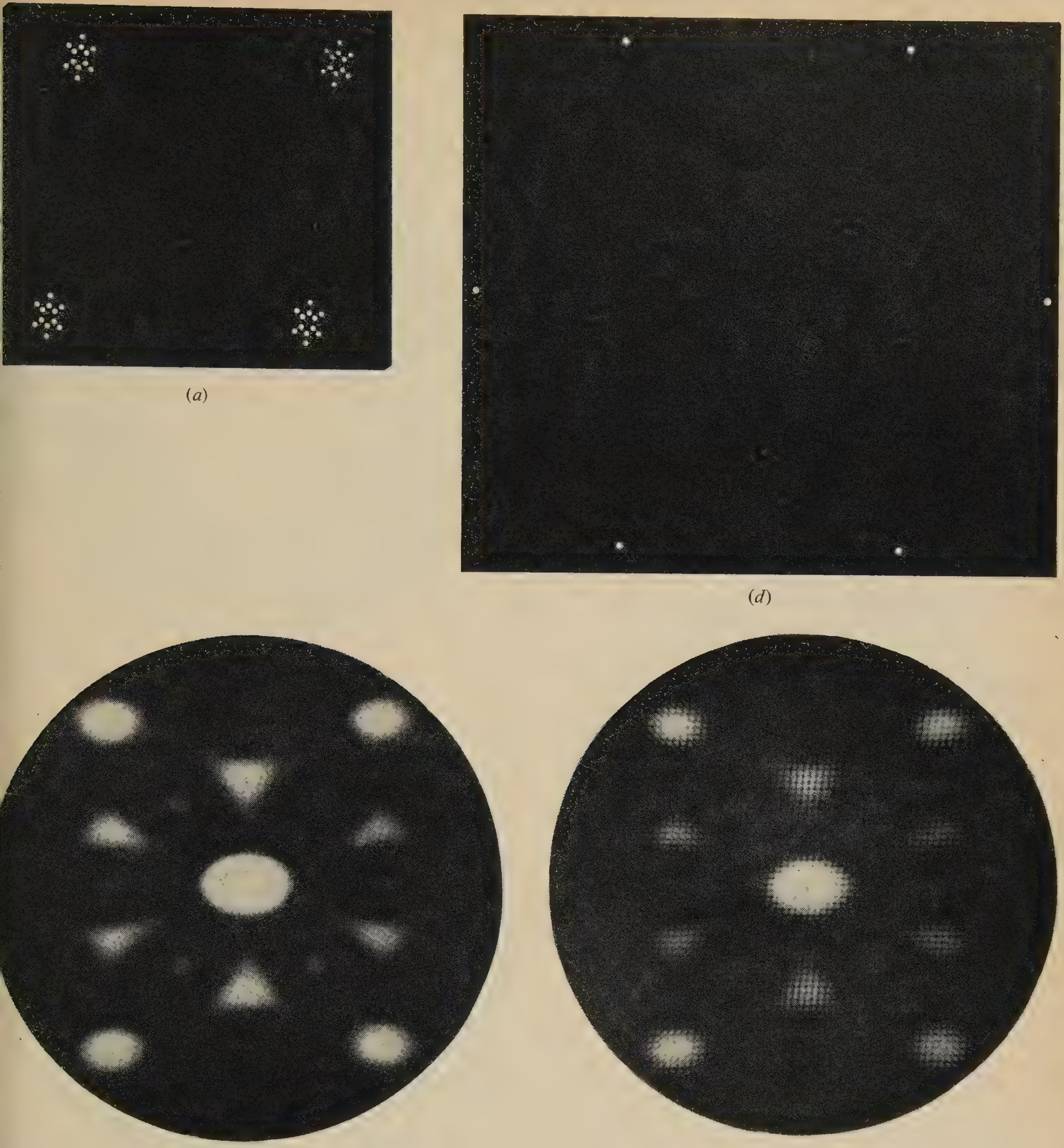
Table 4. *Variation with pinhole diameter of the maxim diameter of punched area of mask for acceptable results*

Diameter of pinhole (μ)	$h_{0{\cdot}5}$ (*cm*)
30	2·2
15	4·2
10	6·4
7·5	8·4
5	12·8

It must be stressed, however, that if the best possib pictures are required it is advisable to use a size smaller pin hole than that indicated by the chart.

Table 4 is calculated for lenses of 5 ft focal length and m be applied directly in this case. Otherwise the values of h in Table 4 will have to be scaled by the ratios of the foc lengths since $h_{0{\cdot}5}$ is directly proportional to the focal leng of the lens L_1 (Fig. 1).

Incorrect choice of pinhole can result in poor pictures wi poor resolution of the peaks. Fig. 10 gives two examples the optical transforms taken with a 30 μ pinhole and the with a smaller pinhole as dictated by the chart. In Fig. 10(no fringes are visible. In Fig. 10(e) the holes are incoherent illuminated with respect to each other so their intensiti simply add and no interference takes place. Figs. 10(



(*a*)

(*d*)

(*b*)

(*c*)

Fig. 10. Illustrations of the effect of pinhole size on the diffraction pattern of two typical masks

(*a*) Mask (actual size).
(*b*) Diffraction pattern of (*a*) with 30 μ pinhole.
(*c*) Diffraction pattern of (*a*) with 7·5 micron pinhole.
(*d*) Mask (actual size).

l (*f*) give the corresponding diffraction patterns with a μ pinhole.

erhaps more important is the example given in Fig. 11. e mask used is shown in Fig. 11(*a*); the holes are separated a distance such that, for a 250 μ pinhole, they have a gative value of γ_{12} (see Fig. 8). It will be seen that the nge system is reversed compared with Fig. 11(*c*) for which 00 μ pinhole was used. The poor visibility of the fringes Fig. 11(*b*) is because the value of g_{12} is only 0·16.

4. SOME BENEFICIAL CHANGES IN THE INSTRUMENT

In order to allow for fine focusing, the centre of the camera table has been made adjustable by the use of a fine screw thread of thirty-two turns per inch. Whilst this does not solve the problem completely it enables a much more critical adjustment to be made.

To obtain more illumination the electrical supply to the lamp has been changed from a.c. to d.c. With d.c. two bright

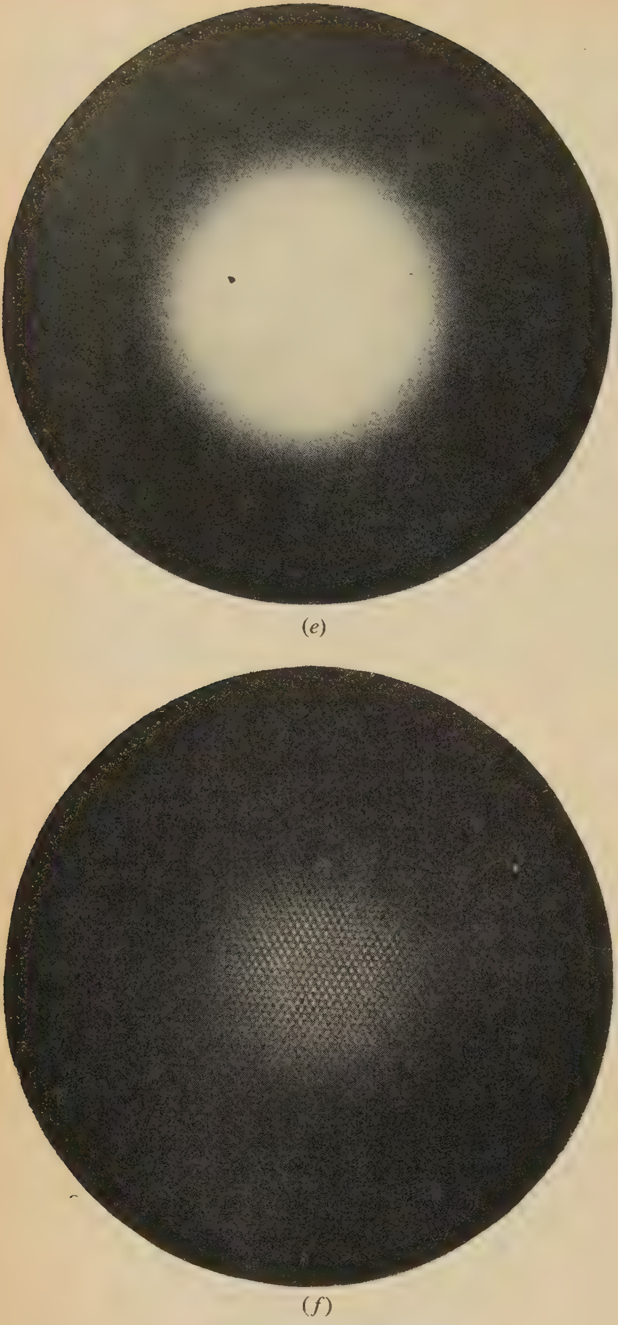


Fig. 10. Illustrations of the effect of pinhole size on the diffraction pattern of two typical masks (*continued*)

(*e*) Diffraction pattern of (*d*) with 30 μ pinhole.
(*f*) Diffraction pattern of (*d*) with 7·5 μ pinhole.

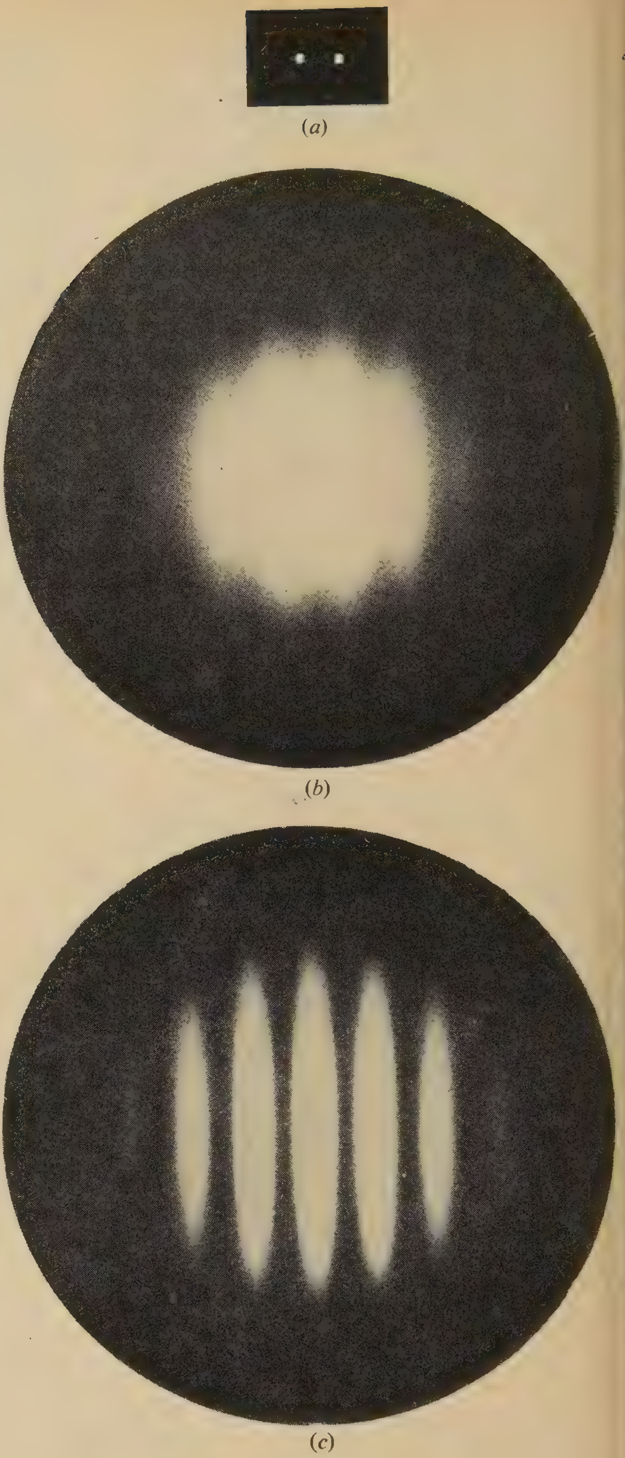


Fig. 11. Illustrations of the change in sign of γ_{12}

(*a*) Mask (actual size).
(*b*) Diffraction pattern of (*a*) with 250 μ pinhole (note the central minimum).
(*c*) Diffraction pattern of (*a*) with 100 μ pinhole (note the central maximum).

cathode spots are still obtained, but one is much brighter than the other. If the brighter spot is focused on to the pinhole then the result is an increase in intensity by a factor of about two.

Two new instruments have been constructed from steel throughout to eliminate differential expansion, since one of the earlier instruments gave some trouble which was traced to the use of brass tubes for some of the stays. Coupled with this the whole instrument has now been made more rigid by the use of steel tie bars in a cantilever system.

For the best photographic results it has been found necessary to use an interference filter centred on the mercur yellow line. This gives better results than the ordinar gelatine filter but does increase the exposure time.

Condensation on the lenses has often caused trouble an avoid this the part of the instrument round the lenses has en boxed in and a small silica gel dryer placed inside. If ndensed water vapour is allowed to remain on a bloomed s for more than a few hours it leaves a permanent mark d the phase of the beam passing through is slightly modified.

5. PHOTOGRAPHIC TECHNIQUE

The time taken to punch masks and place them in the fractometer is so short that, in obtaining optical transforms, photographic processing is the main factor in determining total time involved. It has, therefore, become important cut down the processing time to a minimum; this has been hieved by the use of modern rapid developers and fixers. e requirements for the photographic work are small grain e, reasonable contrast, short exposure and development ne, combined with control of the processing.

Until recently Leitz two-bath developer(12) has been used in njunction with an ammonium thiosulphate fixing bath. lox developer or D8 has been used where greater contrast required. A series of tests has recently been carried out on rious types of films and developers, the results of which given in Table 5.

ACKNOWLEDGEMENTS

It is our pleasure to express our thanks to Dr. E. Wolf, of the Physics Department, University of Manchester, for his keen interest in this work and for his invaluable help with some of the theoretical problems concerning partial coherence. We should also like to express our gratitude to Prof. Lipson for his helpful discussions.

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Table 5. *Comparison of various combinations of films and processes*

	Test 1	*Test 2*	*Test 3*	*Test 4*
Film	(Kodak) Pan Microfile	Pan Microfile	Pan Microfile	Quick finish
Developer	Leitz two-bath	Velox	Quick finish	Quick finish
Fixer	Ammonium thiosulphate	Ammonium thiosulphate	Quick finish	Quick finish
Stop bath	2% acetic	2% acetic	None needed	None needed
Total time	11 min	3 min	50 s	50 s
Grain size	Small	Fairly small	Small	Too large
Control	Good	Good	Fairly good	Fairly good
Contrast	Good gradation	Higher than 1	As 1	Fair
Sensitivity	1 and 2 are about equal; 3 and 4 give twice the sensitivity of 1 and 2			

From the table it will be seen that the most useful combina- n is given by test 3. This cuts down the processing time the negative to 50 s. Prints may be made directly before shing. It was found that a development time of 20 s at ° C and a fixing time of 30 s at the same temperature were table. No significant change in the density of the negative s recorded for an error of ±2 s in the development time. itz two-bath and D8 developers still have their advantages special purposes.

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A low frequency random signal generator

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Conventional random signal sources such as photo-multipliers, gas discharge tubes, etc., although good at medium and high frequencies are unreliable at frequencies below about 50 c/s, due to flicker effect. The paper describes a simple method of generating a low frequency random signal having a spectrum extending down to zero frequency, and using a gas discharge tube as the primary noise source. The gas discharge tube has been chosen because of the relatively large noise power available, for instance, this may be 10 V r.m.s. in the band spectrum up to 10^7 c/s. The probability distribution of the resulting signal approaches a Gaussian form. The difference from a true Gaussian is very small and may be neglected in most experimental work.

INTRODUCTION

gas discharge tube will provide Gaussian noise having a spectrum extending down to about 50 c/s. A portion of s spectrum in the high audio frequency range is selected a narrow band filter with central frequency f_0. The output of the filter has the appearance of a sine wave of frequency f_0 but with randomly varying amplitude, the frequency of the fluctuations being of the order of the bandwidth of the filter. Peak rectification of this signal yields a low frequency waveform with a spectrum extending down to zero frequency.

Since the output of a peak rectifier can never reverse polarity, the low frequency waveform will have a d.c. component, and its instantaneous amplitude will always be greater than zero. The actual amplitude distribution is found to be Rayleighan. If two statistically independent signals of this type are added together such that their d.c. components cancel, the result is a random signal having a symmetrical distribution about zero amplitude, and this approaches the Gaussian distribution very closely. The spectrum of the combined signal again extends down to zero frequency, the upper cut-off being determined by the bandwidth of the band-pass filters. Fig. 1 is a schematic diagram of the complete system. It is permissible to use a single noise source since the outputs of the two filters will be statistically independent if their pass bands are sufficiently separated.

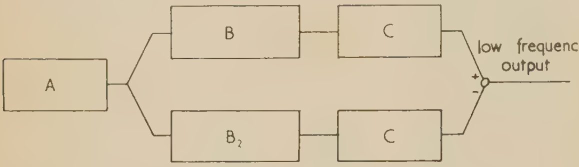

Fig. 1. Schematic diagram of low frequency noise generator

A, wide band Gaussian noise source; B_1, narrow band filter centre frequency f_1; B_2, narrow band filter centre frequency f_2; C, peak rectifier with smoothing.

BANDWIDTH AND PROBABILITY DISTRIBUTION

A random noise signal $x(t)$ may be represented$^{(1)}$ by the sum of a large number of sinusoidal components with random phase relationships, thus

$$x(t) = \sum_{n=1}^{N} c_n \cos(\omega_n t + \phi_n) \tag{1}$$

the ϕ_n's being uniformly distributed in the range 0–2π. If $x(t)$ is the output of a filter subject to a wide band white noise input, then the c_n's of equation (1) are determined solely by the frequency characteristic of the filter as follows,

$$c_n = |G(\omega_n)|\Delta\omega \tag{2}$$

where $G(\omega)$ is the transfer function of the filter, and $\Delta\omega$ is the increment in frequency between the components of the series.$^{(1)}$

Equation (1) may be written,

$$\begin{aligned} x(t) &= \sum_{n=1}^{N} c_n \cos(\omega_n t - \omega_0 t + \phi_n + \omega_0 t) \\ &= y_1 \cos\omega_0 t - y_2 \sin\omega_0 t && (3) \\ &= R\cos(\omega_0 t + \theta) && (4) \end{aligned}$$

where

$$\left.\begin{aligned} y_1(t) &= \sum_{n=1}^{N} c_n \cos[(\omega_n - \omega_0)t + \phi_n] \\ y_2(t) &= \sum_{n=1}^{N} c_n \sin[(\omega_n - \omega_0)t + \phi_n] \end{aligned}\right\} \tag{5}$$

and

$$\left.\begin{aligned} R(t) &= \sqrt{(y_1^2 + y_2^2)} \\ \theta(t) &= \tan^{-1}\frac{y_2}{y_1} \end{aligned}\right\} \tag{6}$$

If $G(\omega)$ is the transfer function of a fairly narrow band filter, and ω_0 represents the mid-band frequency, equation (4) implies that the signal $x(t)$ may be considered as a carrier wave of frequency ω_0 modulated by a slowly varying function of time $R(t)$. From equations (5) we see that $y_1(t)$ and $y_2(t)$ have similar amplitude spectra which are identical with the original band-pass filter spectrum but with a shift of the frequency origin to ω_0, so that the mid-band response of the filter now represents the amplitude of the zero frequency components in y_1 and y_2.

By the central limit theorem y_1 and y_2 must approach normal amplitude distributions since each is the sum of a large number of independent random variables. Demodulation of $x(t)$ by multiplication by a signal $2\cos\omega_0 t$ yields the low frequency component $y_1(t)$ plus higher frequency components which can be filtered off. This would be a convenient method for the generation of low frequency Gaussian signals,$^{(2)}$ but it suffers from certain practical disadvantages. Firstly, it is necessary to ensure an extremely high degree o frequency stability in both the tuned filter and the local oscillator supplying the demodulating signal, since any frequency drift would introduce unpredictable and intolerable fluctuations in the output signal. Secondly, the demodulator if of the electronic type, is liable to introduce d.c. drift whilst mechanical chopper type of demodulators limit the highest carrier frequency which can be used. To overcome these disadvantages the present system employs a simple peak detector. This is found to introduce negligible d.c. drift but unfortunately the amplitude distribution is no longer normal.

AMPLITUDE DISTRIBUTION FOR $R(t)$

As pointed out in the previous section, the amplitude distributions of both y_1 and y_2 must approach the Gaussian form with the same standard deviation σ.

$$p(y_1) = p(y_2) = p(y) = \frac{1}{\sqrt{(2\pi)}\sigma} e^{-y^2/2\sigma^2} \tag{7}$$

where

$$\sigma^2 = \sum \tfrac{1}{2} c_n^2 = \overline{x^2} \tag{8}$$

Also, since $\overline{y_1 y_2} = 0$, the joint probability of y_1 and y_2 is simply the product of their separate probabilities. The probability that the signal $R = \sqrt{(y_1^2 + y_2^2)}$ lies within the elementary rectangle y_1, $y_1 + dy_1$, y_2, and $y_2 + dy_2$ may be written,

$$P(y_1 y_2) = \frac{1}{2\pi\sigma^2} e^{-(y_1^2 + y_2^2)/2\sigma^2} dy_1 dy_2$$

Changing from rectangular to polar co-ordinates we have from equation (6),

$$y_1^2 = y_2^2 = R^2$$

$$dy_1 dy_2 = R dR d\theta$$

$$P(y_1 y_2) = P(R\theta) = \frac{1}{2\pi\sigma^2} e^{-R^2/2\sigma^2} R dR d\theta$$

Integrating this expression over all values of θ from 0–2π we arrive at the probability distribution with respect to R alone.

$$\left.\begin{aligned} p(R) &= \frac{1}{\sigma^2} R e^{-R^2/2\sigma^2}, & R > 0 \\ &= 0 & R < 0 \end{aligned}\right\} \tag{9}$$

This is the Rayleigh distribution* and is plotted in Fig. 2

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* This distribution is also known as Circular Gaussian.

) is seen to have a finite probability of reaching very large plitudes, but it can never cross the zero amplitude level. combining two signals of this type such that their d.c.

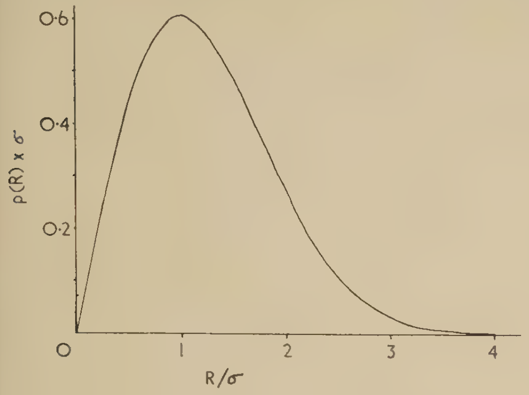

Fig. 2. The Rayleigh probability distribution

$$p(R) = \frac{1}{\sigma^2} R e^{-R^2/2\sigma^2}$$

nponents cancel, a symmetrical distribution is obtained ich is almost normal.

DISTRIBUTION OF THE OUTPUT SIGNAL

The theoretical distribution obtained by combining two yleigh distributions cannot be expressed explicity in terms

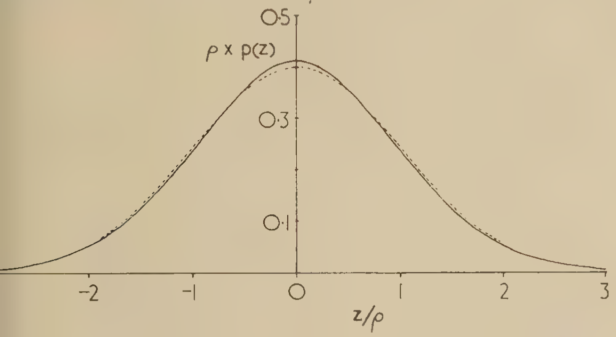

Fig. 3. Theoretical distribution for z together with the normal curve

- - - - - normal distribution $\frac{1}{\sqrt{(2\pi)}\rho} e^{-z^2/2\rho^2}$

——— theoretical distribution of z.

of the signal amplitude. The distribution can be written thus,

$$p(z) = \frac{e^{-a}}{\sqrt{(2\psi)}} \left\{ \Gamma_\infty(\tfrac{3}{2}) \left[1 - \frac{\Gamma_a(\frac{3}{2})}{\Gamma_\infty(\frac{3}{2})} \right] - a\Gamma_\infty(\tfrac{1}{2}) \left[1 - \frac{\Gamma_a(\frac{1}{2})}{\Gamma_\infty(\frac{1}{2})} \right] \right\}$$

where $$a = \frac{z^2}{2\psi}$$

and $$\Gamma_a(n) = \int_0^a t^{n-1} e^{-t} dt.$$

The function $\Gamma_a(n)$ is an incomplete gamma function and has been tabulated by Pearson.$^{(4)}$ The distribution $p(z)$ is plotted in Fig. 3 together with a normal distribution, each curve being normalized with respect to its r.m.s. value. The departure from the ideal distribution is seen to be so small that it may be neglected entirely in most experimental work.

THE PRACTICAL SYSTEM

The primary noise source is an argon filled thyratron operating in a magnetic field$^{(3)}$ with heater and h.t. voltages

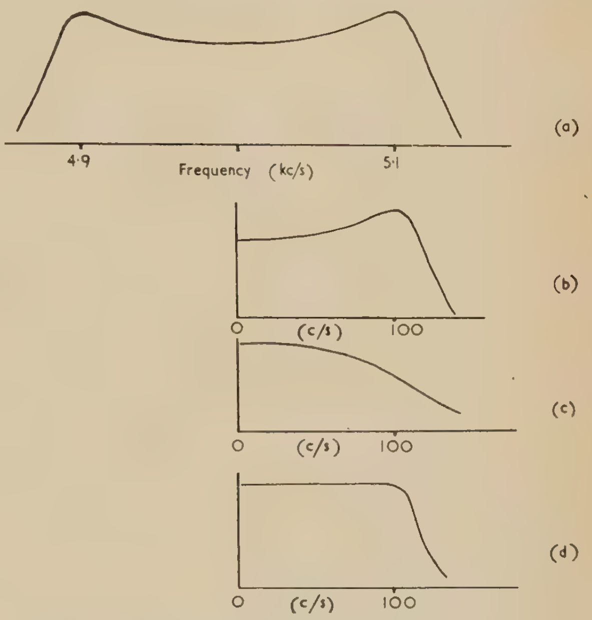

Fig. 4. Filter response and output noise spectrum

(*a*), filter pass band characteristic; (*b*) spectrum of signal at output of rectifier; (*c*) response of low pass R-C filter and (*d*) overall response at output of noise generator.

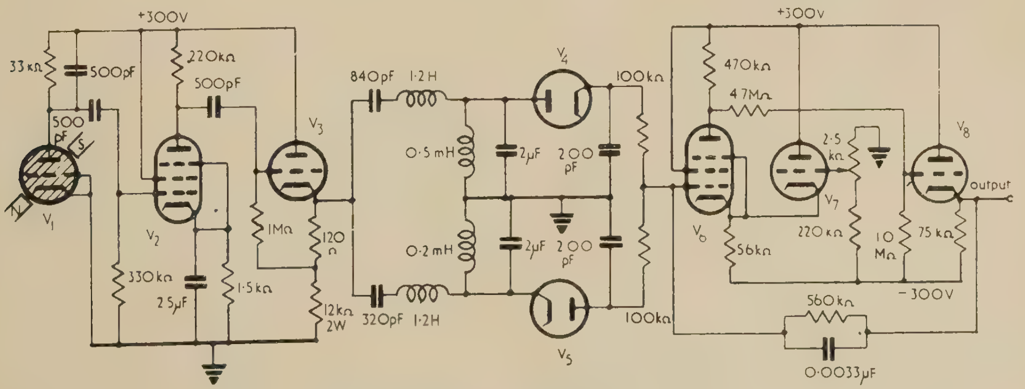

Fig. 5. Circuit diagram of low frequency noise generator

V_1, 6D4; V_2, 6AM6; V_3, 2 × ½ 12AT7; V_4, V_5, 6AL5; V_6, 6AM6; V_7, V_8, 12AT7.

stabilized in order to minimize fluctuations in noise power. The band-pass filters are simple half-sections centred at 5 kc/s and 8 kc/s. The overall bandwidth of each filter is of the order of 250 c/s. The frequency characteristics are not flat topped but rise by about 3 dB at each edge. This gives a low frequency noise signal which rises to a peak at about 100 c/s. The rectifiers are followed by a low frequency R-C filter which cuts off at about 100 c/s. This causes the overall frequency characteristics of the noise to be flat up to 100 c/s and then fall away at higher frequencies. The details of the filters are shown in Fig. 4. It is seen that the spectrum of the output signal is fairly well defined and cuts off rapidly above 100 c/s. This characteristic is obtained without elaborate low-pass filters which usually require unrealistic values of inductance at low frequencies. The complete circuit diagram is given in Fig. 5. This again demonstrates the simplicity of the system.

CONCLUSION

A simple random signal generator is described and shown to give a signal spectrum extending down to zero frequency and an amplitude distribution approaching the normal curve sufficiently close to be of use in a wide variety of experimental applications. The device was originally developed for use with an analogue computer, and provides a continuous source of random disturbances for statistical investigation of the behaviour of dynamic systems.

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The time behaviour of logarithmic amplifier input circuits

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[*Paper first received* 24 *April, and in final form* 20 *June*, 1957]

The non-linear nature of the logarithmic amplifier input circuit causes the time constant to vary with current, and three definitions of effective time constant are examined, based on an analysis of the time behaviour of the input circuit to a step change of input current.

In nuclear reactor instrumentation systems it is usual practice to measure neutron flux by means of a logarithmic amplifier, which measures the current from an ionization chamber acting as a neutron flux detector. The logarithmic characteristic is desirable for two reasons: (*a*) the output of the logarithmic amplifier, when the input is rising exponentially with time, can be differentiated to give a measure of the reactor doubling time, and (*b*) wide range of flux level can be presented on a single meter or recorder scale.

The logarithmic characteristic is obtained by using the exponential voltage-current relationship of a diode operating in the retarding field region,$^{(1)}$ or the grid voltage-grid current relationship of a pentode valve,$^{(2)}$ using the screen grid of the pentode to maintain automatically the anode current at a constant value. The following discussion uses the diode as a model, although the argument will apply equally well to the pentode circuit.

The principle of the method is shown in Fig. 1, which gives the equivalent input circuit of the logarithmic amplifier. The voltage v across the diode is given in terms of the diode current i by

$$i = i_0 \exp (ev/k\theta) \qquad (1)$$

where i_0 is a constant characteristic of the diode, e is the electronic charge, k is Boltzmann's constant and θ is the cathode temperature of the diode. The diode current i is derived from the ionization chamber which is a constant current device. Therefore the grid of the amplifier assumes a voltage v given by equation (1).

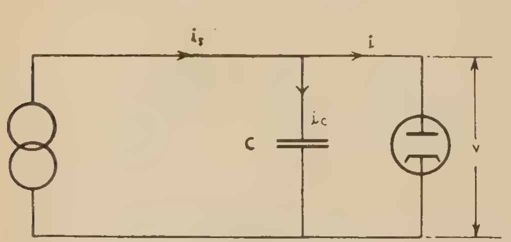

Fig. 1. Equivalent input circuit of logarithmic amplifier

In any practical system the constant current source of the ionization chamber is shunted by capacitance. This is due to the self-capacitance of the chamber itself and the capacitance of the cable carrying the signal from the chamber to the logarithmic amplifier. Thus there will be a time delay in the response of the amplifier to changes in signal current. However, because of the non-linear relationship of input current and voltage this time delay cannot be assessed in terms of the time constant associated with a capacitance-resistance circuit, since there exists no constant resistance across the capacitance. It is possible, of course, to define an instantaneous time constant as the product of the capacitance and the differential resistance dv/di at a particular value of current. From equation (1), by differentiation we have

$$R = dv/di = k\theta/ei \qquad (2)$$

so that the time constant T is given by

$$T = Ck\theta/ei \qquad (3)$$

Although this is satisfactory as a definition of the time constant at a given value of current, it is of little use when nsidering the time behaviour of the current rising from a ue i_1 to a new level i_2, because the time constant as defined l decrease with current. It is proposed, therefore, to amine ways in which a time constant can be defined to e this non-linearity into account.

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One method of defining the time constant would be to e the mean of T given by equation (3) from i_1 to i_2. Thus mean T would be

$$T_e = \int_{i_1}^{i_2} T di \Big/ \int_{i_1}^{i_2} di = \left(\frac{Ck\theta}{e} \log \frac{i_2}{i_1}\right) \Big/ (i_2 - i_1)$$

$$= \left(\frac{Ck\theta}{e} \log m\right) \Big/ [i_1(m-1)] = T_1 \log m/(m-1) \quad (4)$$

ere $m = i_2/i_1$ and T_1 is the initial instantaneous value of at $i = i_1$. Curve (a) of Figs. 2 and 3 gives $\log m/(m-1)$ values of m from 1 to 10 and 10 to 100.

However, a more practical definition would perhaps be to ine the time constant in terms of the time required for the rent to reach a given fraction of its final value. For mple, if the amplifier was a conventional linear d.c. plifier where the input current developed a voltage across ixed grid resistance R, the current i through the resistor a step change in the current source from i_1 to i_2 would be en by

$$i = i_1 + (i_2 - i_1)[1 - \exp(-t/CR)] \quad (5)$$

d the time constant CR defined as the time taken for the rrent to rise to a value

$$i = i_1 + (i_2 - i_1)[1 - (1/e)] \quad (6)$$

Using this as a definition, a value for an effective time nstant can be derived, but first it is necessary to investigate time behaviour of the logarithmic amplifier input circuit. Referring to Fig. 1, i_s is the signal current, i_c is the capacitive rent and i is the current input of the logarithmic amplifier. e differential equation governing the behaviour of i with ne t is deduced as follows:

$$i_s = i_c + i$$

$$i_c = C(dv/dt)$$

om equation (1)

$$dv/dt = (1/Ki)(di/dt)$$

erefore $$i_s = (C/Ki)/(di/dt) + i$$

erefore $$di/dt - (Ki_s/C)i = -(K/C)i^2 \quad (7)$$

This is a form of Bernoulli's differential equation, the ution of which, for a step change in i_s from i_1 to i_2 at $t = 0$, given by

$$i = mi_1/[1 + (m-1)\exp(-at)] \quad (8)$$

ere $m = i_2/i_1$, $a = Ki_2/C$, and $K = e/k\theta$.

Considering the linear case governed by equations (5) and and using the same limits of current i_1 and i_2, an effective ne constant T_e may be defined for the logarithmic case by uating equations (6) and (8) and putting $t = T_e$ in uation (8). Equating and solving for T_e gives

$$T_e = T_1(1/m)\log_e[1 + (e-1)m] \quad (9)$$

ere T_1 is the initial instantaneous value of the time constant Ki_1 at $i = i_1$.

Thus although the instantaneous time constant is inversely oportional to current, the effective time constant for a finite change in current is a less simple function of the ratio of final to initial value of current. Curve (b) of Figs. 2 and 3 gives the function

$$(1/m)\log e[1 + (e-1)m]$$

for values of m from 1 to 10 and 10 to 100.

Curve (a) of Fig. 4 shows the response of current against time for the case of $m = 2$ and $T_1 = 10$ s, and for comparison, curve (b) shows the response of a linear circuit of constant CR

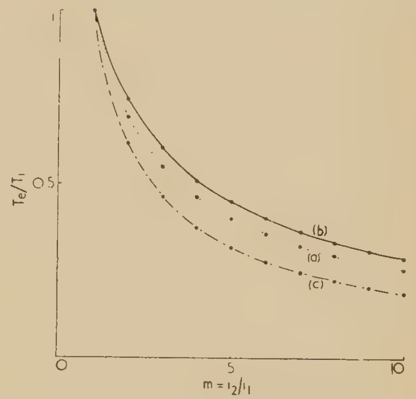

Fig. 2. Variation of T_e/T_1 with m

Curve (a), $1/(m-1)\log_e m$; curve (b), $(1/m)\log_e[1 + (e-1)m]$; curve (c), $(1/m)\log_e[(m-1)/(m^{1/e} - 1)]$.

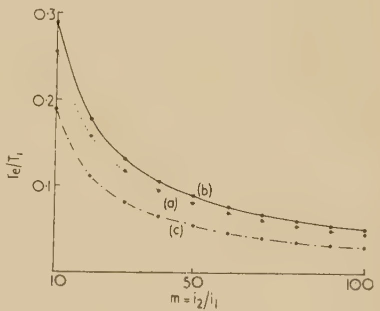

Fig. 3. Variation of T_e/T_1 with m

Curve (a), $1/(m-1)\log_e m$; curve (b), $(1/m)\log_e[1 + (e-1)m]$; curve (c), $(1/m)\log_e[(m-1)(m^{1/e} - 1)]$.

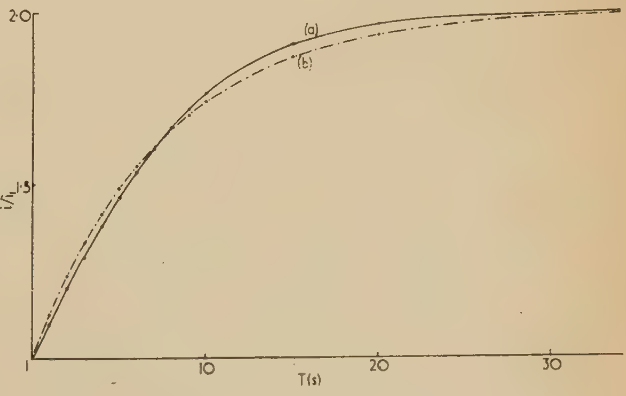

Fig. 4. Time response of input current for $m = 2$

Curve (a), logarithmic amplifier current response, $T_1 = 10$ s, $T_e = 7{\cdot}45$ s; curve (b), linear amplifier current response, $CR = 7{\cdot}45$ s.

with the same current excursion $i_2 - i_1$, and a value for CR of 7·45 s given by equation (9).

The above considerations have led to a definition of effective time constant in terms of the time taken for the current to rise to a given fraction of its final value. It could be argued that the time constant should be defined in terms of the amplifier grid voltage, since it is an amplified version of this voltage that actuates the final indicator or recorder. A definition involving voltages may be deduced in a manner analogous to the above.

From equations (1) and (8), the voltage behaviour with time is given by

$$v = \frac{1}{K}\log_e\frac{i}{i_0} = \frac{1}{K}\log_e\frac{i_1}{i_0} - \frac{1}{K}\log_e\frac{[1+(m-1)\exp(-at)]}{m}$$

$$= v_1 - \frac{1}{K}\log e\frac{(1+(m-1)\exp(-at)]}{m} \qquad (10)$$

Now for the linear case with constant CR,

$$v = v_1 + (v_2 - v_1)[1 - \exp(-t/CR)] \qquad (11)$$

so that the time constant is defined as the time taken for v to rise to a value

$$v = v_1 + (v_2 - v_1)[1 - (1/e)] \qquad (12)$$

Assuming the same voltage excursion from v_1 to v_2, a time constant T_e may be defined for the logarithmic case by equating equations (10) and (12), putting $t = T_e$, and substituting

$$v_2 - v_1 = (1/K)\log_e m$$

Solving this expression for T_e gives

$$T_e = \frac{1}{a}\log_e\frac{m-1}{m^{1/e}-1} = T_1\frac{1}{m}\log_e\frac{m-1}{m^{1/e}-1} \qquad (13)$$

where T_1, as before, is the initial instantaneous time constant at $i = i_1$. A curve of the function $\frac{1}{m}\log_e\frac{m-1}{m^{1/e}-1}$ is shown in curve (c) of Figs. 2 and 3 for values of m from 1 to 10 and from 10 to 100.

Curve (a) of Fig. 5 shows the voltage response of the logarithmic circuit for $m = 2$ and an initial instantaneous time constant of ten seconds. The basis of the construction of this curve is as follows.

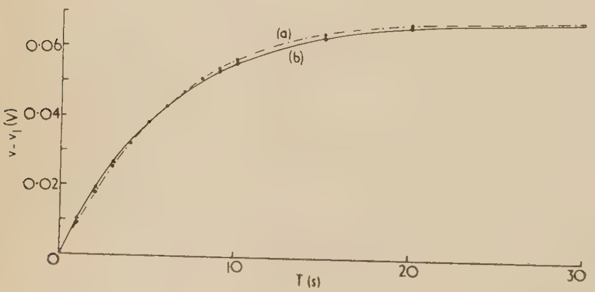

Fig. 5. Time response of grid voltage for $m = 2$

Curve (a), logarithmic amplifier voltage response, $T_1 = 10$ s, $T_e = 6{\cdot}19$ s; curve (b), linear amplifier voltage response, $CR = 6{\cdot}19$ s.

From equation (1)

$$v = \frac{1}{K}\log i/i_0 = \frac{1}{K}\left(\log\frac{i_1}{i_0} + \log\frac{i}{i_1}\right)$$

$$= v_1 + \frac{1}{K}\log\frac{mi}{i_2}$$

$$= v_1 + \frac{1}{K}\log m - \frac{1}{K}\log[1 + (m-1)\exp(-at)]$$

$$= v_1 + \frac{1}{K}\log_e 2 - \frac{1}{K}\log_e[1 + \exp(-at)]$$

for $m = 2$.

Now $K = e/k\theta$

and substituting $e = 1{\cdot}59 \times 10^{-19}$ C and $k = 1{\cdot}374 \times 10^{-23}$ J/°K, K becomes

$$K = (11{\cdot}56 \times 10^3)/\theta\ \mathrm{V}^{-1}$$

If a typical value of cathode temperature is taken as 1150° K then K assumes a convenient value of ten, so that

$$v = v_1 + \tfrac{1}{10}\log_e 2 - \tfrac{1}{10}\log_e[1 + \exp(-at)]$$

and the total voltage excursion for $m = 2$ becomes

$$v_2 - v_1 = \tfrac{1}{10}\log_e 2 = 0{\cdot}0693\ \mathrm{V}$$

Equation (11) gives the voltage response of a linear circuit of constant CR and substituting the same value of voltage excursion 0·0693 V leads to curve (b) of Fig. 5, where the time constant of 6·19 s used to compute curve (b) is given by equation (13), putting $m = 2$ and $T_1 = 10$ s.

The above considerations have led to three definitions of effective time constant for the logarithmic amplifier input circuit. Of these, the author favours the definition given by equation (13) for the voltage response, since, as previously mentioned, it is the diode voltage which actuates the final indicator. The decrease of time constant with increase in current is a fortuitous advantage in some applications, as for example, in the case of a nuclear reactor. Under conditions of shut-down the neutron flux may still be measurable by means of an ionization chamber but the noise level associated with the signal, due to reactor noise, to noise in the amplifier and to statistical fluctuations in the rate of arrival of neutrons in the ionization chamber, may be such that a large input time constant is necessary to smooth the response. This may be obtained by placing a suitable capacitor across the input terminals. Such a time constant would, for safety reasons, be prohibitively large at the higher power levels and in the logarithmic amplifier the time constant is automatically reduced as the power level increases.

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Some further results on the rubber membrane theory and Laplace's equation

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Some further results and points are presented to underline the theory of constant horizontal tension of the rubber membrane as discussed in a previous paper by the author.(3) Small deflexion theory which assumes constant resultant tension fails, in the case of coaxial geometry, to account at large deflexions for (*a*) the linear force-deflexion law obtained and (*b*) the close correspondence of the membrane's contour to Laplace's equation. Both observations are successfully predicted by the revised theory which places no limitations on geometry or deflexion for the above two conditions to hold. Experiment also confirmed a linear force-deflexion law for an asymmetric geometry.

is still widely held that the rubber membrane analogue of aplace's equation is valid only to a first order approxiation, and fails to hold if the inclination of the membrane the rest plane xy is too large. Thus assuming, as smallflexion theory does, that the *resultant* tension per unit ngth is, and on deflexion remains, constant ("soap bubble" eory), considerations of minimum surface potential energy ad to the equation

$$\frac{\partial^2 h}{\partial x^2}\left[1+\left(\frac{\partial h}{\partial y}\right)^2\right]+\frac{\partial^2 h}{\partial y^2}\left[1+\left(\frac{\partial h}{\partial x}\right)^2\right]-2\frac{\partial^2 h}{\partial x\partial y}\frac{\partial h}{\partial x}\frac{\partial h}{\partial y} \qquad (1)$$

here h is the coordinate of the membrane perpendicular to e xy plane. Laplace's equation, as can be seen, follows ly if $\partial h/\partial x$ and $\partial h/\partial y$ are small.

For the coaxial case equation (1) leads to(1)

$$h = A\cosh^{-1}(r/A) + B \qquad (2)$$

here r is the radial coordinate. This was still the equation nployed(2) to estimate departures from the Laplacian uation, which is of course given by

$$h = a\log r + b \qquad (3)$$

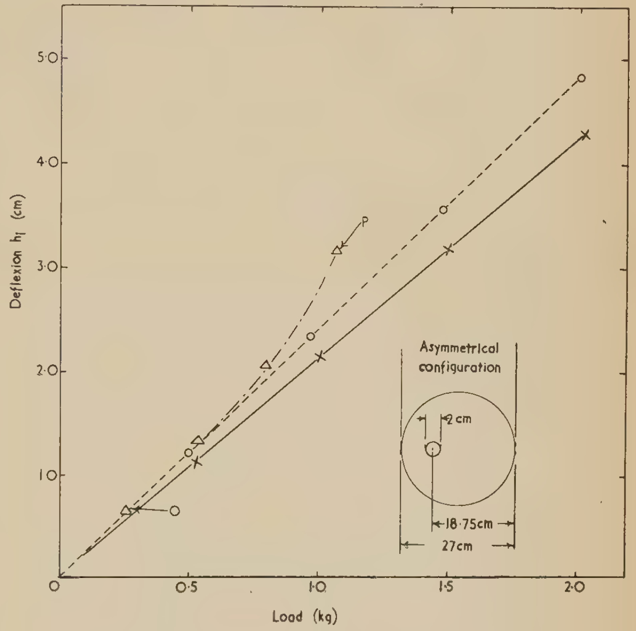
However, even at large deflexions [$\tan^{-1}(\partial h/\partial r) \geqslant \pi/3$], reful experiments showed that in the coaxial case the embrane followed equation (3) much more closely than uation (2); this led to a revision of the theory.

The revised theory(3) postulates that the component tension , in the xy plane remains constant, its definition being given

$$\text{omponent in } xy \text{ plane of resultant force } T\delta s = T_0\delta s_0 \qquad (4)$$

here δs is the line element in the membrane perpendicular, T, δs_0 is its component in the xy plane perpendicular to T_0 d T is the resultant force per unit length of membrane. ius T_0 is not, as has been erroneously supposed, the comnent of T in the xy plane, but only its constancy is given equation (4), where the tensions multiplied by the resultant component line elements of the membrane respectively are pressed as force elements. By considering the equilibrium a small element of the membrane whose projected area the xy plane equals $\delta x\delta y$, Laplace's equation follows for inclinations to the rest plane xy.(3) This theory can erefore account far better for the experimental results tained.

But in addition the revised theory(3) predicts that the flexion perpendicular to the xy plane will follow Hooke's Law, that is, the deflexion h of an "electrode" will be proportional to the force applied to it. The curve quoted(3) was for the coaxial case and has been reproduced in the figure.



Relation between deflexion and applied force

– – – ○ coaxial; ——— × asymmetrical;
—·— △ $F = k\,\text{sech}\,[(h_i - B)/A]$; at P $\partial h_i/\partial r = \infty$.

Further results have emerged(4) which substantiate the revised theory and also indicate how serious the departure from previous theory is. As shown, linearity in the force-deflexion plot was also obtained with the central electrode asymmetrically placed inside the outer electrode and with observed peak inclinations of the membrane greater than $\pi/3$. The lower slope of this curve is due to the increased capacitance of the asymmetric configuration compared with the coaxial case. This can be seen from the equation(3)

$$C = q/h = KF/T_0h \qquad (5)$$

where F = force displacing the electrode, C = capacitance per unit length of the electrical analogue, h = displacement of electrode and K = a constant independent of the geometry of the electrode system. For constant T_0, higher values of C lead to higher values of F for a given displacement h.

The force-deflexion law predicted by previous "soap

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bubble" theory can be calculated in the following way. If F is the deflecting force then

$$F = T \oint \sin \theta ds \tag{6}$$

where T = *resultant* tension, and θ = inclination of the membrane at the electrode, the integration being taken around this electrode. For the coaxial case

$$F = 2\pi T r_i \sin \theta \tag{7}$$

where r_i = radius of inner electrode. Since T is assumed constant

$$F = k \sin \theta \tag{8}$$

where k is a constant independent of the deflexion. Since on previous theory, the exact equation of the membrane's contour for the co-axial geometry is given by equation (2) for all deflexions

$$\partial h/\partial r = A/(r^2 - A^2)^{\frac{1}{2}} = \tan \theta \tag{9}$$

$$\therefore \sin \theta = A/r = \text{sech } [(h - B)/A] \tag{10}$$

$$\therefore F = k \text{ sech } [(h_i - B)/A] \tag{11}$$

where h_i = deflexion of inner electrode which, since

$$\text{sech } h = 1 - \tfrac{1}{2}h^2 + 5/24h^4 \ldots (h^2 < \pi^2/4) \tag{12}$$

certainly does *not* predict Hooke's law. It has been plotted in the figure where, since the constant k is indeterminate, it has been made to coincide at the point O with the experimental curve of the coaxial case where the deflexion h_i is very small.

The point P is the limiting point where according to equation (9) $\partial h_i/\partial r = \infty$ which corresponds to $A = r_i$, the inclination of the membrane at the inner electrode now supposedly being perpendicular to the xy plane.

Clearly the theory of constant resultant T fails to account for the linear force-deflexion law as well as the fact that, at least in the coaxial case, Laplace's equation is followed much more closely than equation (2). Furthermore, deflexions beyond the point P are, on previous theory, ruled out, whereas, in fact, linearity is observed for much larger deflexions.

A point stressed in the previous paper$^{(3)}$ was that if the displacements at the boundaries (electrodes) were in the h direction with no component in the rest plane xy, then all points in the membrane do, as observed, move also only in the h direction. Thus with a plane passing through two fixed points in the membrane and intersecting it in the line element δs connecting the two points, the magnitude of δs would, in general, depend on the deflexion. Its projection in the xy plane δs_0, however, would remain constant for all deflexions and fixed in space. Assuming this observation to be valid, it is not difficult to see why $T_0 \delta s_0$ should remain constant. For assuming the membrane to be a uniformly stretched two-dimensional regular lattice of particles, then if on vertical displacements of the boundaries all parts of the lattice move only vertically, the projected configuration of the lattice in the xy plane should remain constant and so should the projected forces $T_0 \delta s_0$ between the constituent particles.

The properties of such an idealized, two-dimensional lattice require further theoretical investigation. A point of particular interest would be the nature of the forces between the constituent particles in the two-dimensional lattice which when initially uniformly stretched in the xy plane fits the revised membrane theory when displaced along h. Body forces would, of course, be assumed entirely absent, perfect knife edges resulting on folding such a lattice over. A successful solution of this problem could then be applied to the rubber membrane in particular, and should be interpreted in terms of its known elastic properties.

Such properties have of course also consequences for dynamic conditions. If, with the boundaries initially displaced in the h direction, all parts of the membrane move only in the h direction with no components in the xy plane, all wave motion of free or forced vibrations of the membrane should be purely transverse, a point that has so far always been implicitly assumed.

CONCLUSIONS

For the coaxial case examined the linear force-deflexion law obtained cannot be accounted for on previous theory which assumed constant resultant tension ("soap-bubble" theory). This theory predicts a force-deflexion law given by equation (11) which seriously departs, over the range of deflexions measured, from the linear law which was in fact obtained. It also predicts the limiting point P (see figure) where $\partial h_i/\partial r = \infty$, but which experimentally was well exceeded. Also, Laplace's equation given in this case by equation (3) is followed even for large deflexions much more closely by the membranes contour than equation (2) which is derived from previous theory. With the inner cylinder placed asymmetrically (see figure) a linear force-deflexion law was once more obtained, the lower slope correctly corresponding to the increased capacitance of the equivalent electrical analogue. Thus the revised theory of constant T_0 defined by equation (4) correctly accounts for Hooke's law and the fact that Laplace's equation is also followed for large deflexions of the membrane.

ACKNOWLEDGEMENTS

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Fizeau-type interference between beams of light reflected from three surfaces

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Optical interference phenomena between beams of light reflected from three surfaces are described and analysed. The distinctive feature of the fringe system is that the field is crossed by bands of intensity equal to that of light reflected from one of the surfaces, delineating the lines of constant separation of the other two surfaces. The use of the phenomena in metrology is briefly discussed.

new absolute determination of the density of mercury is ing prepared at the National Physical Laboratory by which mass of mercury filling a cubical box of known volume to be found. The box is made by wringing six optically t plates of fused silica into optical contact and its volume found from optical interference measurements of the stances between opposite faces. Two pairs of faces are sily made parallel and the distances between them can be easured using the Fabry-Perot interference system (Haidinger ngs). The third pair of faces cannot so easily be made fficiently parallel for the observation of Haidinger rings d a different method of measurement has therefore been vised.

The cube is placed under the head of a Kösters–Zeiss terferometer. Then, since the cube is transparent, inter- ence can occur between light reflected from the reference irror of the interferometer and from both the internal rfaces, which are arranged to be nearly parallel to the age of the reference mirror; reflexions from the external rfaces of the cube are thrown out of the aperture of the strument by making the angles between the internal and ternal faces large enough. If then the angles between the ference mirror and the cube faces are suitably adjusted, it ight be expected that two sets of interference fringes would obtained, namely, between light reflected from the reference irror and from each of the two internal faces, and that these fringes would intersect at a small angle corresponding to the angle between the cube faces. On viewing this system of fringes (Fig. 1) they are found to be crossed by bands similar to the moiré bands of crossed diffraction gratings. Elementary ideas suggest that these bands mark out contours of equal path difference between the opposite faces of the cube, and they do in fact turn out to be very convenient for measuring the distance between the faces.

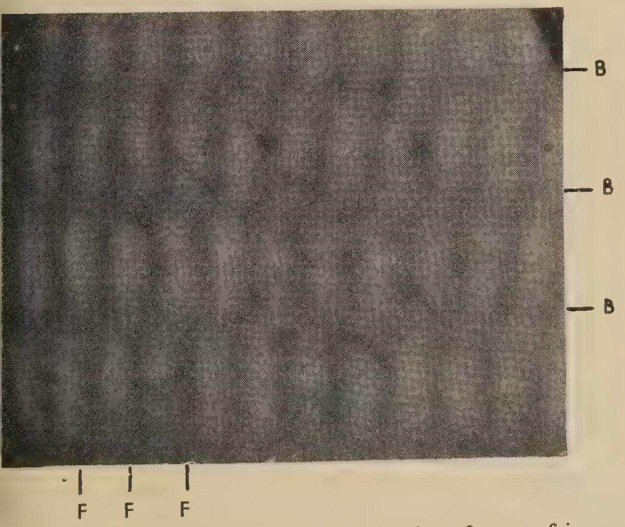

Fig. 1. Photograph of triple-beam interference fringes taken in violet light ($\lambda 4358$) of mercury 198 spectrum. Separation of outer reflectors 7·3 cm ($1{\cdot}7 \times 10^5\ \lambda$)

B, bands of intensity equal to that reflected from reference mirror at constant separation of outer reflectors. *F*, fringes of constant separation of reference mirror and mean plane of outer reflectors.

A detailed analysis of the interference system of the beams from the three surfaces is presented in this paper. Zernike* has previously suggested the use of interference phenomena of three beams.

ANALYSIS OF THE SYSTEM

The notation is indicated in Fig. 2. The upper and lower reflecting planes we call 1 and 2 and the centre plane, formed by the image of the reference mirror of the Kösters interferometer, we call *r*. The distance of the reference plane from plane 1 we call d_r and the separation of planes 1 and 2 we call 2*d*.

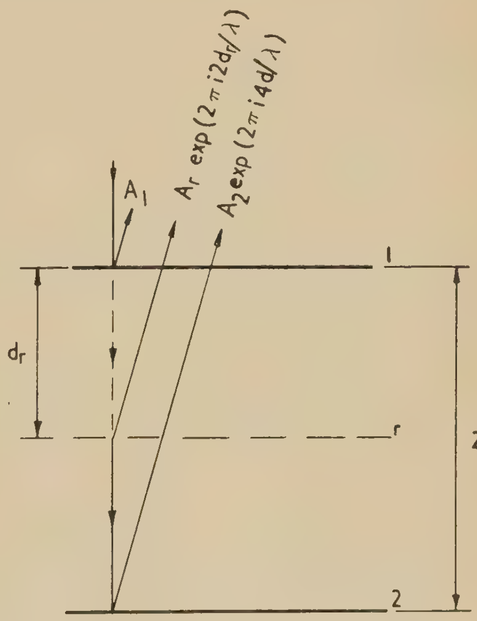
A_1
$A_r \exp(2\pi i 2d_r/\lambda)$
$A_2 \exp(2\pi i 4d/\lambda)$
1
d_r
r
2d
2

Fig. 2. Diagram to show notation

The incident light is supposed to be collimated so that all wave fronts are plane. Multiple reflexions are ignored. The complex amplitudes of the three reflected beams at the upper reflecting plane (where the fringes may be regarded as localized) are then A_1, $A_r \exp(2\pi i \,.\, 2d_r/\lambda)$, and $A_2 \exp(2\pi i \,.\, 4d/\lambda)$, where λ is the wavelength of the light being used.

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* Mercier, R. *J. Opt. Soc. Amer.*, **46**, p. 380 (1956).

The analysis is not restricted to interference in parallel light. Instead of considering the amplitudes at one of the surfaces (in parallel light, it is immaterial which is chosen) we may consider the amplitudes in the focal plane of a lens used to observe the fringe pattern; the same expressions hold save that the amplitudes A_1, A_2, A_r must now each include a term giving the phase shift through the optical system. The same expressions apply for the amplitudes in the focal plane of an observing lens when the light incident on the mirrors is uncollimated.

A three-slit analogue of Young's double slit system may also be imagined; expressions similar to those above are then obtained for the amplitudes of waves at any given point in the half-space illuminated by the slits.

The total amplitude, S, is

$$A_1 + A_r \exp(2\pi i \,.\, 2d_r/\lambda) + A_2 \exp(2\pi i \,.\, 4d/\lambda)$$

If the complex conjugate of S is S^*, the intensity of the light is SS^*.

$$\begin{aligned} SS^* = {} & A_1A_1^* + A_rA_r^* + A_2A_2^* \\ & + A_1A_r{}^* \exp(-2\pi i \,.\, 2d_r/\lambda) + A_1A_2^* \exp(-2\pi i \,.\, 4d/\lambda) \\ & + A_1^*A_r \exp(2\pi i \,.\, 2d_r/\lambda) + A_1^*A_2 \exp(2\pi i \,.\, 4d/\lambda) \\ & + A_rA_2^* \exp(2\pi i \,.\, 2d_r/\lambda) \exp(-2\pi i \,.\, 4d/\lambda) \\ & + A_r^*A_2 \exp(-2\pi i \,.\, 2d_r/\lambda) \exp(2\pi i \,.\, 4d/\lambda) \end{aligned}$$

We now introduce explicitly the phases of the reflexions at the three surfaces, writing

$$A_1 = a_1 \exp(i\phi_1)$$

and so on, where a_1 is real.

Then $A_1A_1^* = a_1^2$ and so on, and

$$\begin{aligned} A_1A_r^* &= a_1a_r \exp[i(\phi_1 - \phi_r)] \\ A_1^*A_r &= a_1a_r \exp[-i(\phi_1 - \phi_r)] \end{aligned}$$

For our immediate purpose we further simplify our analysis by using the fact that reflexion 1 is at a fused silica/air interface and reflexion 2 at an air/fused silica interface, so that $A_1 = -A_2$. We then obtain

$$\begin{aligned} SS^* = {} & 2a_1^2 + a_r^2 - 2a_1^2[1 - 2\sin^2(2\pi \,.\, 2d/\lambda)] - \\ & - 4a_1a_r \sin[(2\pi/\lambda)2(d_r - d) - \Delta\phi] \times \sin[(2\pi/\lambda)2d] \end{aligned}$$

where $\Delta\phi = \phi_1 - \phi_r$.

The intensity is therefore

$$\begin{aligned} a_r^2 + 4a_1\Big\{ & a_1 \sin\left(\frac{2\pi}{\lambda} \cdot 2d\right) + \\ & + a_r \,.\, \sin\left[\frac{2\pi}{\lambda} 2(d - d_r) + \Delta\phi\right]\Big\} \times \sin\left(\frac{2\pi}{\lambda} \cdot 2d\right) \end{aligned}$$

To make the formulae less cumbersome, we put

$$(2\pi/\lambda)2d = \psi$$

and $$(2\pi/\lambda)2(d - d_r) + \Delta\phi = \chi$$

The intensity is then

$$a_r^2 + 4a_1[a_1 \sin\psi + a_r \sin\chi] \,.\, \sin\psi$$

We observe first that when $\psi = n\pi$ or $2d/\lambda = \frac{1}{2}n$ the intensity is a_r^2.

This is the condition that is satisfied along the moiré bands, and it is the same as that satisfied along the dark Fizea fringes that would be formed by light reflected from th surfaces 1 and 2.

If $\sin\psi$ is not zero, let it have the value s. Then th intensity is

$$a_r^2 + 4a_1^2s^2 + 4a_1a_rs \sin\chi$$

If s is positive, this expression has a maximum when sin equals +1, whereas if s is negative, the maximum occurs fo $\sin\chi$ equal to −1. The pattern of the resulting fringes ma be shown by plotting the maxima on a Cartesian grid wit the values of $\sin[(2\pi/\lambda)2(d - d_r) + \Delta\phi]$ as abscissae and th values of $\sin[(2\pi/\lambda)2d]$ as ordinates. Such a diagram i given in Fig. 3. The actual fringe pattern in any particula

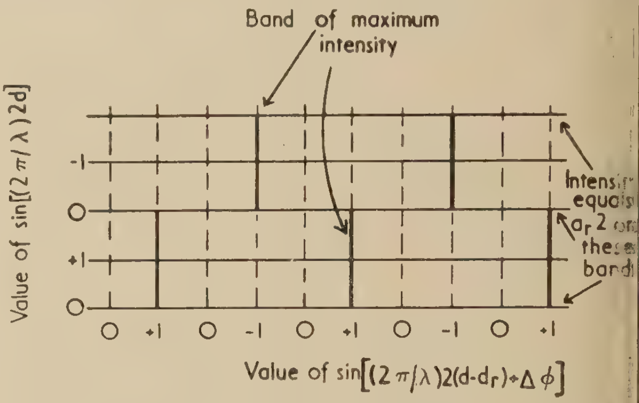

Band of maximum intensity
Value of sin[(2 π/λ)2d]
-1
0
+1
0
0 +1 0 -1 0 +1 0 -1 0 +1
Value of sin[(2 π/λ)2(d-dr)+Δ ϕ]
Intensi equa ar 2 o these band

Fig. 3. Diagram of arrangement of moiré bands and interference fringes

instance is obtained by deforming the rectangular grid int the actual grid of lines of constant d and constant $(d - d_r)$, the photograph of the fringes given in Fig. 1 will easily b interpreted in the light of Fig. 3.

In the general case where A_1 and A_2 are unrelated, we pu $a_m = \frac{1}{2}(a_1 + a_2)$, $a_d = \frac{1}{2}(a_1 - a_2)$, $\phi_m = \frac{1}{2}(\phi_1 + \phi_2)$ an $\phi_d = \frac{1}{2}(\phi_1 - \phi_2)$, and then find for the intensity,

$$\begin{aligned} I = a_r^2 + 4a_m\Big\{ & a_r \cos\left[\frac{2\pi}{\lambda} \cdot 2d_r - (\phi_r - \phi_m)\right] + \\ & + a_m \cos\left(\frac{2\pi}{\lambda} \cdot 2d - \phi_d\right)\Big\} \times \cos\left(\frac{2\pi}{\lambda} \cdot 2d - \phi_d\right) + \\ + 4a_d\Big\{ & a_r \sin\left[\frac{2\pi}{\lambda} \cdot 2d_r - (\phi_r - \phi_m)\right] + \\ & + a_d \sin\left(\frac{2\pi}{\lambda} \cdot 2d - \phi_d\right)\Big\} \times \sin\left(\frac{2\pi}{\lambda} \cdot 2d - \phi_d\right) \end{aligned}$$

If a_m is put equal to zero, a_d equal to a and ϕ_d equal to as in the foregoing analysis, the general expression for reduces to the simpler formula previously obtained.

Let

$$a_r \cos\left[\frac{2\pi}{\lambda} \cdot 2d - (\phi_r - \phi_m)\right] + a_m \cos\left(\frac{2\pi}{\lambda} \cdot 2d - \phi_d\right) = f$$

and

$$a_r \sin\left[\frac{2\pi}{\lambda} \cdot 2d_r - (\phi_r - \phi_m)\right] + a_d \sin\left(\frac{2\pi}{\lambda} \cdot 2d - \phi_d\right) = f$$

$$\tan\alpha = a_mf_c/a_df_s$$

and $$A_m^2 = a^2{}_mf_c^2 + a_d^2f_s^2$$

Then I may be written as

$$a_r^2 + 4A^2 \,.\, \sin\left[(2\pi/\lambda)\,.\,2d - \phi_d + \alpha\right]$$

gain this takes the value $a^2{}_r$ whenever

$$\sin\left[(2\pi/\lambda)2d - \phi_d + \alpha\right]$$

zero, that is, at equal intervals of d, but now these bands cur at a phase $(\alpha - \phi_d)$ which is in general unknown.

VISIBILITY CONSIDERATIONS

The discussion of this section is restricted to the simple oblem in which the reflexion coefficients of the outer lexions are equal in magnitude and of opposite sign: $= -A_2$.

Spectral line of infinitesimal width. For fringes formed in pectral line of infinitesimal width, the intensity I is given by

$$I = a_r^2 + 4a_1^2 s^2 + 4a_1 a_r s \sin\chi$$

d the visibility V, of the fringes of constant $(d - d_r)$ which defined to be $(I_{max} - I_{min})/(I_{max} + I_{min})$, is

$$4a_1 a_r |s|/(a_r^2 + 4a_1^2 s^2)$$

This takes the maximum value of $4a_1 a_r/(a_r^2 + 4a_1^2)$ when s, it is, $\sin[(2\pi/\lambda)2d]$, is equal to $+1$ or -1, and falls to o when s is zero. This behaviour is shown by the fringes Fig. 1.

Visibility with a doublet line. We examine the effect served when the fringes are produced by a doublet, the o components of which have equal intensity.

Let the wavelengths of the doublet be $\lambda - \delta\lambda$ and $\lambda + \delta\lambda$ that the phase angles ψ and χ become $\psi - \delta\psi$, $\chi - \delta\chi$ d $\psi + \delta\psi$, $\chi + \delta\chi$, where

$$\delta\psi = k_1\delta\lambda = -(4\pi d/\lambda^2)\delta\lambda$$

d

$$\delta\chi = k_2\delta\lambda = -(4\pi/\lambda^2)(d - d_r)\,\delta\lambda$$

ıen $I(\lambda - \delta\lambda) = a_r^2 + 4a_1^2\sin^2(\psi - \delta\psi) + {}$

$$+ 4a_1 a_r \sin(\psi - \delta\psi)\sin(\chi - \delta\chi)$$

d $I(\lambda + \delta\lambda) = a_r^2 + 4a_1^2\sin^2(\psi + \delta\psi) + {}$

$$+ 4a_1 a_r \sin(\psi + \delta\psi)\sin(\chi + \delta\chi)$$

d the mean intensity, I_m, due to the two wavelengths gether, is

$$\begin{aligned} &a_r^2 + 2a_1^2[\sin^2(\psi - \delta\psi) + \sin^2(\psi + \delta\psi)] + {}\\ &\quad + 2a_r a_1[\sin(\psi - \delta\psi)\sin(\chi - \delta\chi) + {}\\ &\qquad\qquad + \sin(\psi + \delta\psi)\sin(\chi + \delta\chi)]\\ &= a_r^2 + 2a_1^2(1 - \cos 2\psi\cos 2\delta\psi) + {}\\ &\quad + 4a_1 a_r(\sin\psi\sin\chi\cos\delta\psi\cos\delta\chi + {}\\ &\qquad\qquad + \cos\psi\cos\chi\sin\delta\psi\sin\delta\chi) \end{aligned}$$

$\delta\chi$ (that is, $d - d_r$) is small, I_m is nearly

$$\begin{aligned} &+ 4a_1^2\sin^2\delta\psi + 4a_1^2\sin^2\psi\cos 2\delta\psi + {}\\ &\qquad + 4a_1 a_r\sin\psi\sin\chi\cos\delta\psi\cos\delta\chi \end{aligned}$$

The value of I_m when $\sin\psi$ is zero is now $a^2{}_r + 4a^2{}_1\sin^2\delta\psi$ d the visibility of the fringes when $\sin\psi$ has the value $\pm s$

$$\frac{4a_1 a_r s\,.\,\cos\delta\psi\,.\,\cos\delta\chi}{a_r^2 + 4a_1^2(\sin^2\delta\psi + s^2\cos^2\delta\psi)}$$

Two conclusions of practical importance follow from this formula.

First, the visibility depends essentially on the product of $\cos\delta\psi\cos\delta\chi$. If we assume that the first factor is fixed because the distance $2d$ is fixed, while the second factor is variable because the distance d_r is variable, then we see that for best contrast, d_r should be made equal to d; it is found in practice that if $\cos\delta\psi$ is small the adjustment of d_r is quite critical if fringes are to be seen at all.

Secondly, for given $\delta\chi$, the visibility depends on $\cos\delta\psi$. If, however, two-beam Fizeau fringes were obtained by reflexion from the surfaces 1 and 2, they would have a visibility equal to $\cos 2\delta\psi$; thus, when $\sin\psi$ is equal to $+1$ or -1 [that is, mid-way between the moiré bands where I is equal to $(a_r^2 + 4a_1^2\sin^2\delta\psi)$] and provided the value of a_r is suitably matched to a_1, the visibility of the fringes corresponds to that of Fizeau fringes formed in light reflected from surfaces with half the separation of the surfaces 1 and 2. The same advantage of increased contrast is then obtained as is gained in the conventional measurement of end-gauges with the Kösters-Zeiss interferometer.

Line with Gaussian profile. We suppose that the intensity of the line at a wavelength $(\lambda + \delta\lambda)$ is proportional to $(2\pi\sigma^2)^{-1/2}\exp[-(\delta\lambda)^2/2\sigma^2]$, so that the line profile is centred on λ and has a r.m.s. width of σ.

The intensity of light reflected from the three planes at a wavelength $(\lambda + \delta\lambda)$ being $I(\lambda + \delta\lambda)$, the total intensity of light integrated over the line profile, is

$$(2\pi\sigma^2)^{-1/2}\int_{-\infty}^{+\infty} I(\lambda + \delta\lambda)\exp[-(\delta\lambda)^2/2\sigma^2]\,d\lambda$$

We write $I(\lambda + \delta\lambda)$ in the form:

$$\begin{aligned} &a_r^2 + 2a_1^2(1 - \cos 2\psi\,.\,\cos 2\delta\psi + \sin 2\psi\,.\,\sin 2\delta\psi) + {}\\ &\quad + 2a_1 a_r[-\cos(\psi + \chi)\,.\,\cos(\delta\psi + \delta\chi) + {}\\ &\qquad\qquad + \cos(\psi - \chi)\cos(\delta\psi - \delta\chi)] + {}\\ &\quad + 2a_1 a_r[\sin(\psi + \chi)\,.\,\sin(\delta\psi + \delta\chi) - {}\\ &\qquad\qquad - \sin(\psi - \chi)\sin(\delta\psi - \delta\chi)] \end{aligned}$$

and we observe that the integrals are of two types: those in which the integrand is $(\cos k\,\delta\lambda)\exp[-(\delta\lambda)^2/2\sigma^2]$ and those in which it is $(\sin k\delta\lambda)\exp[-(\delta\lambda)^2/2\sigma^2]$, where k is either $(k_1 - k_2)$ or $(k_1 + k_2)$. The latter integrand is odd and vanishes for the limits $-\infty$ and $+\infty$; we therefore have to consider only those integrals with the cosine terms.

Now

$$\int_{-\infty}^{+\infty}(\cos k\,\delta\lambda)\exp[-(\delta\lambda)^2/2\sigma^2]d\lambda = \sqrt{(2\pi)}\sigma\exp(-k^2\sigma^2/2)$$

The integrated intensity is therefore

$$\begin{aligned} &a_r^2 + 2a_1^2[1 - \cos 2\psi\exp(-2k^2{}_1\sigma^2) + {}\\ &\qquad + 2a_1 a_r\{-\cos(\psi + \chi)\,.\,\exp[-\tfrac{1}{2}(k_1 + k_2)^2\sigma^2] + {}\\ &\qquad + \cos(\psi - \chi)\,.\,\exp[-\tfrac{1}{2}(k_1 - k_2)^2\sigma^2]\} \end{aligned}$$

that is

$$\begin{aligned} &a_r^2 + 2a_1^2[1 - \exp(-2k_1^2\sigma^2)] + 4a_1^2\sin^2\psi\,.\,\exp(-2k_1^2\sigma^2) + {}\\ &\quad + 4a_1 a_r[\sin\psi\sin\chi\cosh(\tfrac{1}{2}k_1 k_2\sigma^2) + {}\\ &\quad + \cos\psi\cos\chi\sinh(\tfrac{1}{2}k_1 k_2\sigma^2)] \times \exp[-\tfrac{1}{2}(k_1^2 + k_2^2)\sigma^2] \end{aligned}$$

If now $k_1 k_2\sigma^2$ is small, the term $\cos\psi\cos\chi\sinh(\tfrac{1}{2}k_1 k_2\sigma^2)$ may be ignored and once again the moiré bands, now of intensity $a^2 + 2a^2[1 - \exp(-2k_1^2\sigma^2)]$, occur when $\sin\psi$ is zero. The visibility of the fringes when $\sin\psi$ has the value $\pm s$ is

$$\frac{4a_1 a_r s \exp[-\tfrac{1}{2}(k_1+k_2)^2\sigma^2]}{a_r^2 + 2a_1^2[1 - \exp(-2k_1^2\sigma^2)] + 4a_1^2 s^2 \exp(-2k_1^2\sigma^2)}$$

Again, for maximum visibility, the value of $(d - d_r)$, that is, of k_2, should be made as small as possible.

If the value of $(d - d_r)$ is not small, the moiré bands are displaced and, for a doublet, occur when

$$a_1 \cos 2\delta\psi \sin^2\psi + a_r \sin\chi \cos\delta\psi \cos\delta\chi \sin\psi + \\ + a_r \cos\chi \sin\delta\psi \sin\delta\chi \cos\psi$$

vanishes, while for a Gaussian profile they occur when

$$a_1 \exp(-2k_1^2\sigma^2)\sin^2\psi + a_r \exp[-(k_1^2 + k_2^2)\sigma^2] \times \\ \times [\sin\chi \cosh(\tfrac{1}{2}k_1k_2\sigma^2)\sin\psi + \cos\chi \sinh(\tfrac{1}{2}k_1k_2\sigma^2)\cos\psi]$$

vanishes.

The approximate solutions are

$$\sin\psi = -\cot\chi \tan\delta\psi \tan\delta\chi$$

or

$$\sin\psi = -\cot\chi \tanh(\tfrac{1}{2}k_1k_2\sigma^2)$$

respectively and, in each case, $\sin\psi$ is proportional to

$$d(d - d_r)/[(d - d_r) + (\lambda\Delta\phi/4\pi)].$$

$\Delta\phi/4\pi$ cannot exceed $\pi/2$ and so, except when $d - d_r$ is less than $\lambda/2$, the displacement is nearly independent of $d - d_r$ and has the value $4\pi d\,.\,(\delta\lambda)^2/\lambda^3$ for the doublet, or $2\pi\, d\, \sigma^2/\lambda^3$ for the Gaussian profile.

For metrological applications, since it is not easily possible to make $d - d_r$ less than many half-wavelengths, $d(\delta\lambda)^2/\lambda^3$ or $\sigma^2 d/\lambda^3$ must be less than about 5×10^{-3} if the systematic displacement of the moiré bands is to be less than one-twentieth of the fringe separation. Thus, for example, if d/λ is 150 000, $\delta\lambda/\lambda$ must be less than $\sqrt{3} \times 10^{-4}$, or $\delta\lambda$ rather less than 1 Å for visible light. Since a much smaller separation or width than this is necessary to obtain good visibility over such a path length, σ/λ being of the order of 10^{-6} for lines used for metrological purposes, the band displacement should, in practice, never cause trouble.

Reflexion coefficients for maximum visibility. It will easily be seen that for a spectral line of infinitesimal width, the visibility when $\sin\psi$ takes the values ± 1 has its maximum value of 1 if a_r is equal to $2a_1$.

If the line has a finite width or is a doublet, the general expression for the visibility, V, when $\sin\psi$ is ± 1, is

$$4a_1 a_r \alpha/(a_r^2 + 4a_1^2\beta)$$

where for the doublet,

$$\alpha = \cos\delta\psi \cos\delta\chi$$

and

$$\beta = \cos^2\delta\psi$$

while for the Gaussian profile,

$$\alpha \doteq \exp[-\tfrac{1}{2}(k_1 + k_2)^2\sigma^2]$$

and

$$\beta = \tfrac{1}{2}[1 + \exp(-2k_1^2\sigma^2)]$$

provided $d - d_r$ is small.

The maximum visibility then occurs when $a_r^2 = 4a_1^2\beta$ and has the value $\alpha\beta^{-1/2}$, that is $\cos\delta\chi$ for the doublet and $\cosh^{1/2}(k_1^2\sigma^2)\,.\,\exp[-\tfrac{1}{2}k_2(2k_1 + k_2)\sigma^2]$ for the Gaussian profile.

If, for example, for a Gaussian profile, $\sigma = 10^{-6}\lambda$, a representative value for lines used in metrology, and if d/λ is $7{\cdot}5 \times 10^4$ (corresponding to a length slightly less than 4 cm when λ is about 5000 Å) then $k_1\sigma$ is about 1, $\exp(-2k_1^2\sigma^2)$ is 0·14 and β is nearly 0·6. The maximum visibility is then attained if $a_r^2 = 2{\cdot}4a_1^2$; it is, in fact, clear that unless $k_1\sigma$ is much less than 1, β is close to 0·5 and the best value to choose for a_r for general use is $\sqrt{2}\,.\,a_1$.

With $k_1\sigma$ equal to 1, α is about 0·61 and the visibility of the fringes mid-way between the moiré bands is $(0{\cdot}6)^{1/2}$, that is 0·77.

METROLOGICAL USE OF THE FRINGES

The main metrological value of these fringes is that their contrast is much greater than that of two-beam Fizeau interference fringes produced by light reflected from the upper and lower surfaces. It is not possible to assign a single numerical value to the contrast of the moiré bands, but the precision with which their positions can be defined is enhanced over that of the Fizeau fringes by two factors, first, the fringe structure of the field between the moiré bands helps in locating the centres of the bands, and secondly, the contrast of the fringes mid-way between the moiré bands corresponds to a path difference of half the actual path difference between the outer reflectors.

The bands could, naturally, be produced with other arrangements of reflectors and beam dividers and could be used to measure the distance between transparent surfaces which were not sufficiently parallel to give Haidinger rings, Edser–Butler bands or channelled spectra.

ACKNOWLEDGEMENTS

The occurrence of the moiré bands was first noticed by Mr. N. W. B. Stone who also took the photograph shown in Fig. 1.

This investigation forms part of the research programme of the National Physical Laboratory and this paper is published by permission of the Director of the Laboratory.

Laboratory and workshop notes

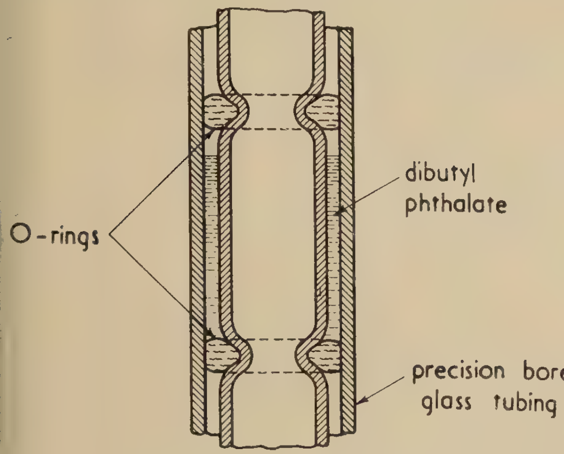
A simple glass sliding joint for vacuum work

3y G. W. Gore, B.E., A.M.I.E.E.,* Division of Metro-
ogy, National Standards Laboratory, Chippendale, New
South Wales, Australia

Note first received 1 May, and in final form 21 June, 1957]

ring the development of a mercury barometer, difficulties re experienced in the use of p.v.c. and polythene tubing, as se materials were found to degas continuously under uum. In order to overcome these difficulties a glass ling joint was developed. As it was simple to construct yet very effective, a description might be helpful to others.

The figure shows that two grooves have been provided in smaller of the two tubes and suitably chosen Neoprene -rings” are placed into the grooves. In order to retain od sealing properties, the grooves were made in a glass he and the outer tube was of precision bore glass.



Details of glass sliding joint

Tests have been carried out and show that the joint, when ricated with di-butyl phthalate, is suitable for systems at ssures of the order of 1 μ. The di-butyl phthalate, filled o the annular space between the “O-rings” with a hypo- mic syringe, facilitates sliding. When the glass diameters properly chosen the force required to cause sliding is prisingly small.

Now at Mullard Research Laboratories, Salfords, Surrey.

A fast cycle furnace

By D. B. Irving, B.Sc., Weapons Research Establishment,
Salisbury, South Australia

[Note received 4 April, 1957]

many laboratory heat treatment operations in an oxygen- e atmosphere, a great saving of time can be effected if the nace can be deprived of its insulation and thus cooled idly. We have successfully used a tube furnace which vides this facility by employing removable, friable fire- ck insulation.

The bricks, which are 9 in. square and 2¾ in. thick, are soft ough to cut with a power hacksaw blade. To prepare them ole large enough to accommodate the furnace tube with winding is drilled through the centre of each brick, so that when a number of bricks are stacked together a tunnel is formed into which the furnace tube may be placed and effectively insulated. By cutting the bricks in halves through the axis of the hole, the upper half-bricks may be removed leaving the furnace tube open to the air, and thus in a condition where rapid cooling will result. The windings on the tube may be held in position by filling the spaces between them by any suitable refractory cement. Such a furnace, consisting of 19 s.w.g. Kanthal wire on a 3 cm diameter mullite tube, was cooled from 1200 to 200° C in 25 min.

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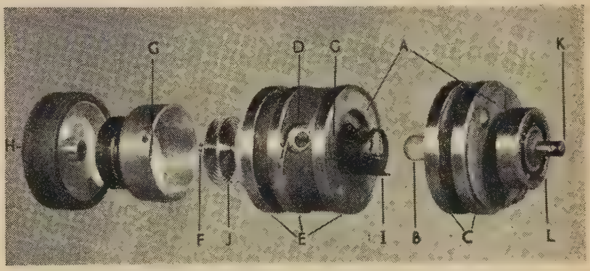
A rotating torque switch operable by light yarns

By R. L. Pocock, M.A., The Hosiery and Allied Trades
Research Association, Nottingham

[Note received 8 April, 1957]

Measurement of yarn velocity is difficult where very light yarns are used, because there is little energy available from the yarn. It is important in research on knitted fabrics to be able to maintain a selected ratio of yarn velocity to machine velocity. This device has therefore been developed to detect variations in the velocity of a yarn or filament relative to an angular velocity.

A barrel *A* borne on trunnions is free to rotate about its axis within an outer casing (not shown). The barrel is made in two parts. In one is mounted a miniature lamp *B* from which connexions are made to two slip-rings *C* on the outside of the barrel. In the other are sunk two photo-conductive cells *D*, with connexions made to three slip-rings *E* on the outside of the barrel, and also a shaft *F* lying axially within the barrel borne on miniature ball bearings. These are not visible in the photograph, but are located at the places indicated *G*. The shaft projects through the trunnion, and to its outer end is attached a light pulley *H*, while to its inner end is fixed a shutter *I*. The shaft is thus free to rotate within the barrel, but its movement is restricted by a stop acting on the shutter, and by two spiral springs *J* attached to the shaft and barrel. When the two parts of the barrel are assembled, the shutter enshrouds the lamp and prevents light from falling on the photocells. However, the shutter is cut away in part so that a rotation of the pulley in one direction relative to the barrel allows one photocell to be illuminated, and a rotation in the opposite direction allows the other photocell to be likewise illuminated. The spring loading and stops are arranged so that, with zero torque on the pulley,



Rotating torque switch shown in expanded form the shutter is centrally disposed relative to the photocells, and neither is illuminated.

Spring loaded carbon brushes are mounted in a housing attached to the outer casing and make contact with the five slip-rings on the surface of the barrel. Electrical connexions are taken from these brushes.

Thus the barrel may be rotated within its casing by turning the spigot *K* projecting through the ball bearing *L* forming the trunnion at the end opposite to the pulley. With the barrel, the two photocells, lamp, shutter, shaft, miniature ballraces, hair springs and pulley also rotate. But any torque applied to the pulley, whether the barrel is at rest or not, will displace the shutter relative to the photocells, and, if this torque is sufficiently large to overcome the effect of the spring-loading, one photocell or the other will be illuminated. It is clear that although angular acceleration of the barrel will have an effect on the displacement of the shutter relative to the photocells, angular velocity will not, since the bearings of the shaft are supported within the barrel.

If a yarn or filament engages the pulley surface and it does not slip, its velocity, neglecting transients, is given by

$$Y = \pi dR/12$$

where Y is the yarn velocity in ft/min, d is the diameter of the pulley in inches, and R is the angular velocity of the barrel in rev/min. If it is ensured that the frictional forces at the surface, relative to the strength of the hair springs, are sufficient to ensure illumination of either photocell before slip occurs, the device will give an electrical indication of departure of yarn velocity from the value $\pi dR/12$. The device may thus be used to detect and control the ratio Y/R, i.e. the velocity of a yarn relative to an angular velocity.

The photo-conductive cells used are Hilger Type FT422 Schwarz cells, and the lamp is a 12 V L.E.S. Philips pea lamp. The diameter of the pulley in the photograph is one inch.

For light yarns, e.g. 30 denier nylon, the diameter of which is 0·0025 in., the spring loading is such that the photocells are illuminated before the frictional force at the pulley surface reaches 0·25 g wt.

Adjustable apertures for electron diffraction cameras

By J. C. Mills, Chemical Physics Section, Division of Industrial Chemistry, Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia

[*Note received* 16 *April*, 1957]

Two types of symmetrically opening square aperture for use in electron diffraction cameras are described.

Type 1 is designed to operate inside a magnetic lens at a relatively inaccessible back focus and the aperture is therefore situated at the top of a vertical column. The controls for centreing and adjusting the aperture are brought out through the vacuum in the plane of the base of the column.

The column *A*, shown in Fig. 1, of $\frac{1}{2}$ in. outside diameter ×16 gauge brass tube, is mounted on a square base *B* and carries four vertical slots spaced at 90°. At a point three-fifths of the way up the tube there is a circumferential groove for a wire circlip. Translation of the arms *C* along the slots is prevented by the vee notch near the centre of each arm which engages with the circlip. The arms are retained in the slots by two small springs *D* which also serve to return the aperture to the closed position. The top of each arm carries a thin horizontal platinum jaw. Opposite pairs of jaws are located in planes separated by the thickness of the ja material, i.e. 0·002 in. The lower ends of the arms are contact with the conical sleeve *E*, which may be raised

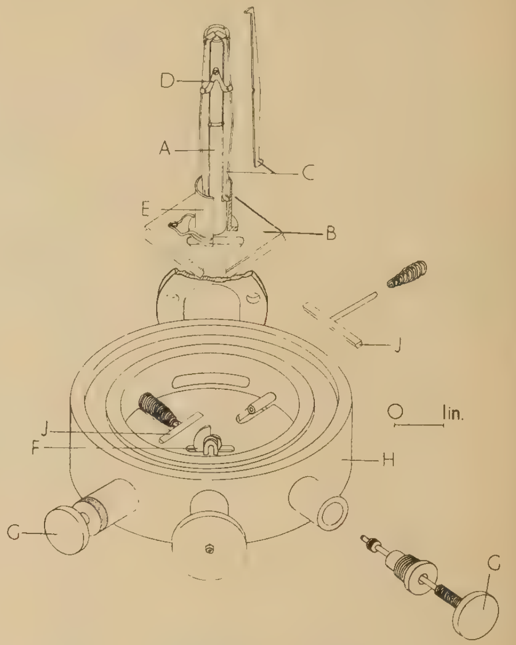


Fig. 1. Adjustable aperture. Type 1

lowered by the cam *F* to open or close the aperture. Centrei of the aperture is effected by two orthogonal push rods acting on the base *B* through grommet seals in the outer ca The base is held firmly against the flat plate in the bottom the outer case *H* and the push rods *G* by the action of sloping faces of the spring loaded pressure pads *JJ* on inclined faces of the base *B*.

Type 2 has been used at a more accessible focal pla between two lenses. In this design the four platinum ja are mounted on dovetail sliders *A* of which three only a shown in Fig. 2. The sliders may move along the tw

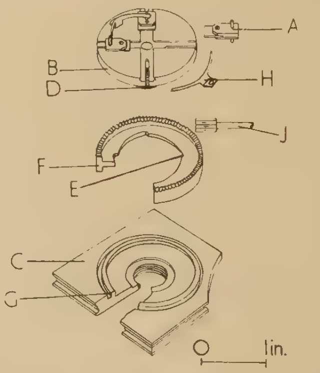


Fig. 2. Adjustable aperture. Type 2

diametral ways in the disk *B*, which is firmly attached to base *C* by a hollow screwed boss *D*. A crown wheel wi cam *E* fits between *B* and *C* and is located in the groove Each slider carries a pin engaging with one of the fo operating surfaces of the cam *E* carried by the crown whe *F* which may rotate in the circular groove *G* in the base Rotation of the cam is limited to a little less than 90°. Tw f springs *H* acting on the upper end of the pins drive the ders *A* outwards so that the pins are always in contact with cam faces. Opposite pairs of jaws are arranged to be in ntact when the cam is in its extreme clockwise position. tation of the cam may be effected by the pinion *J* which disengaged by withdrawing it along its axis whenever the ntreing controls are used. The aperture is mounted in an ter case with centreing controls identical with those scribed in Fig. 1.

The performances of the two types of aperture are equally od and the apertures remain sensibly square when closed less than 10 μ.

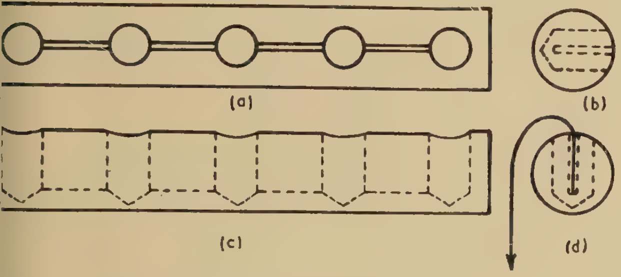
The author wishes to thank Dr. J. M. Cowley for his couragement and advice.

A reservoir for paper chromatography for use inside a rectangular glass container

By A. L. Sims, University of Wales, Cardiff

[*Note received* 30 *May*, 1957]

ur views of a reservoir made from a polythene rod are own in the figure. The polythene rod is 2 in. in diameter d is made long enough to fit sufficiently accurately to be ld, without fastening, between the opposing walls at the



Reservoir made from a polythene rod

(*a*) Plan view, (*b*) Side view, (*c*) Elevation, (*d*) Side view; the arrow indicates the position the paper would occupy in use.

p of a rectangular glass container. Five 0·5 in. diameter les drilled to a depth of 1·75 in. and at 90° to the rod axis connected by a slot 0·125 in. wide and 1·7 in. deep, thus king one reservoir.

The paper is placed in the slot and allowed to hang down side the rectangular glass container; no clips are necessary; o papers can be used with each reservoir and more than e reservoir can be used in each chromatographic container. varying the number of holes in each polythene rod the pacity of the reservoir can be predetermined to suit dividual requirements.

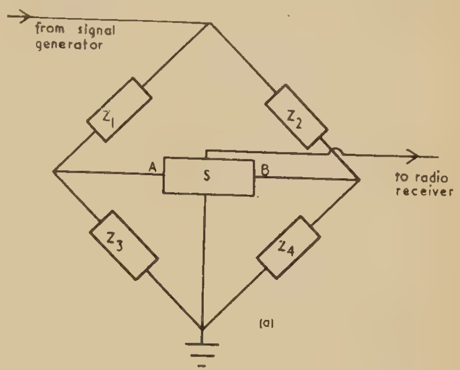
A "subtractor" for radio-frequency bridges

By E. A. Faulkner, Research Laboratories of The General Electric Co. Ltd., Wembley, Middlesex

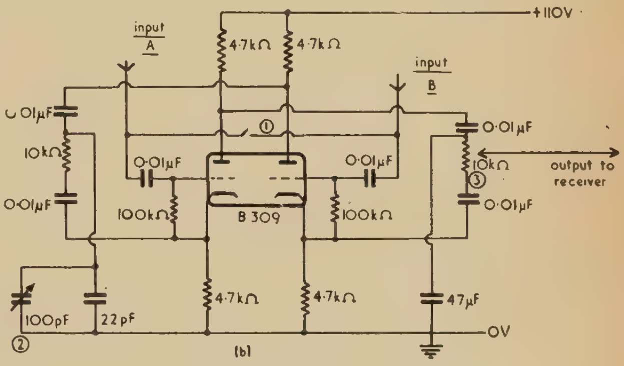
[*Note received* 12 *July*, 1957]

simple electronic device has been developed to overcome balance difficulties usually associated with radio-frequency idges; it has two identical high-impedance input terminals d gives an output proportional to the vector difference between their potentials with respect to earth, which can be fed into a normal receiver.

Before a measurement is to be made, the bridge is connected to the r.f. supply (see figure), the switch (1) is closed and the trimming controls (2) and (3) are adjusted so that no signal is detected in the receiver. (This adjustment must normally be repeated for each frequency, and is quite simple at frequencies up to 5 Mc/s.) Switch (1) is then opened, and the bridge is adjusted so that no signal is detected; the two input terminals of the subtractor are now at the same potential and the bridge is in balance.



(*a*) Diagram of bridge
S, subtractor



(*b*) Circuit diagram of subtractor

Notes on the continuous recording of radiation using the Moll thermopile

By F. A. Burden, Ph.D., and A. Hoffman, Gas Council, London Research Station, Watson House, London, S.W.6

[*Note first received* 21 *March, and in final form* 10 *May*, 1957]

In the measurement of the radiation output from solid fuel or gas fires for the purpose of appliance efficiency or fuel performance testing it is common practice to use the N.P.L. pattern Moll thermopile in conjunction with a suitable sampling arrangement. The intensity of radiation measured by the thermopile varies, but in certain cases may be as high as 800–900 B.t.u. $ft^{-2}h^{-1}$. At this level of intensity an error is introduced if the thermopile is exposed to the radiation for more than a few minutes, and precautions must be taken to shield the thermopile element, when measurements are not actually being taken. The effect of temperature upon the response of the Moll thermopile has been investigated by Morpurgo.(1)

The error caused by the heating of the cold junctions of the thermopile when this is exposed continuously to radiation intensities of the order of 600 B.t.u. ft^{-2} h^{-1} may amount to 3–5% of the intensity recorded. This effect is of some importance when comparing the performance of different solid fuels on the open fire and especially when it is desired to measure the maximum radiation output attained. For this purpose the continuous recording of radiation is most desirable. To overcome this limitation of the instrument the use of an electrically operated shutter to expose the thermopile for a short period at regular intervals has been recommended, with some success, but this device suffers from the disadvantage of a limiting frequency of operation, and of possible mechanical failure. It was therefore decided to investigate the practicability of an alternative solution to the problem. This consisted in maintaining the cold junctions of the thermopile at a constant temperature in the neighbourhood of room temperature by artificial cooling.

For this purpose an N.P.L. pattern Moll thermopile was modified by removing the back cover plate and fitting in its place a hollow brass chamber (Fig. 1) through which a stream of water could be passed. When in position, the face of the chamber was about 8 mm from the cold junctions of the thermopile, so that slight variations in water temperature were not transmitted directly to the cold junctions, while the cool back was effective in removing heat from the interior of the thermopile. A stand was set up to hold a thermopile in a standard sampling position in front of a coke fire, and the radiation intensity as indicated by a normal thermopile continuously exposed to the radiation was plotted at intervals of 5 min. Between these readings, the thermopile was displaced without shielding it from the radiation, and a second thermopile placed in the same sampling position. This thermopile was used as a reference instrument, and a similar series of readings was obtained, exposing the thermopile only for the minimum time required to measure the radiation. A further series of tests was carried out using the modified thermopile continuously exposed to the radiation. A slow stream of water, which was maintained at constant temperature, was passed through the chamber, and the results compared with those given by the reference thermopile as before. Tests were carried out at several water temperatures in the range 12 to 22° C, room temperature in each case being about 25° C. All thermopiles used were checked before use against a sub-standard.

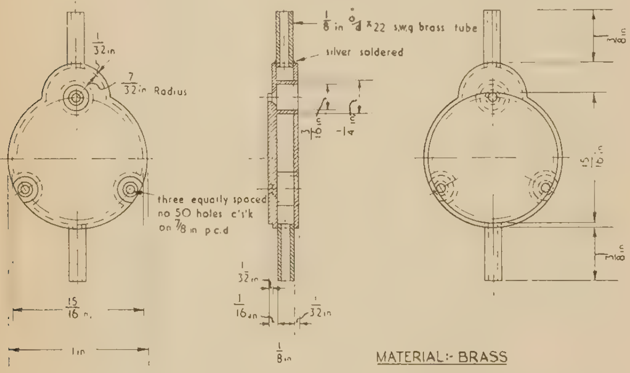


Fig. 1. Water-cooled back for Moll thermopile; material, brass

The accompanying graphs, Fig. 2, which are typical of t results obtained demonstrate that in the modified thermop the error due to continuous exposure which may amount some 5% at a radiation intensity of 600 B.t.u. ft^{-2} h^{-1} almost completely eliminated, and this holds for cooling wat temperatures in the range 3 to 10° C below room temperatur

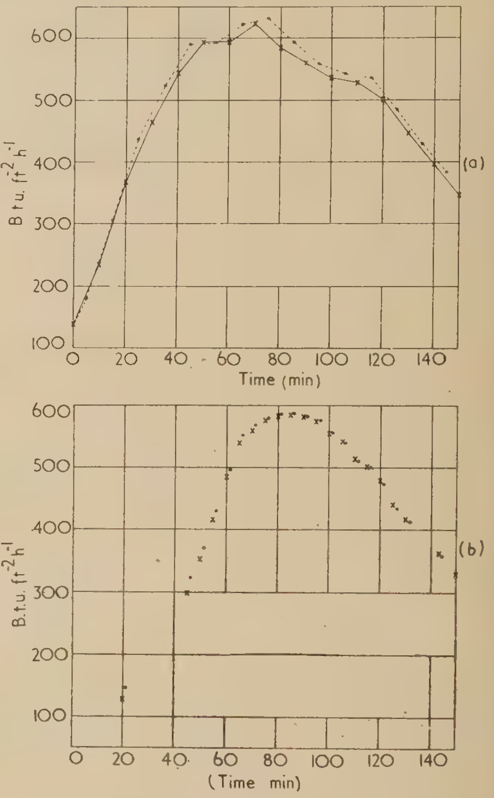


Fig. 2. Measurement of radiation by continuously exposed Moll thermopile

(*a*) . . ● . . reference thermopile.
—×— exposed thermopile.
(*b*) · · · reference thermopile.
× × × water-cooled thermopile.

Mean temperature of water 22° C; mean temperature of air 25° C.

Tests with a small copper-constantan thermocouple showe that the back of the case of a normal Moll thermopile co tinuously exposed may attain a temperature in the regic of 35° C, so that the improvement in performance resulte from the cooling of the case by 15 to 25° C. Under the conditions the temperature variation normally occurring in mains water supply have no effect on the performance of tl modified thermopile, and no close control of water te-perature is required. This system of compensation permi truly continuous recording of radiation, is inherently reliab and has had a useful application in the performance testi of solid fuels.

The authors wish to thank the North Thames Gas Boa for facilities and the Gas Council for permission to publi this work.

REFERENCE

(1) MORPURGO, P. W. R. *Gas Council Res. Comm. No. GC* (1955).

A single-flash rotary disk optical shutter

By R. L. GREGORY, M.A., Psychological Laboratory, Cambridge

[*Note first received* 23 *May, and in final form*, 2 *August*, 1957]

is often necessary, for example, for physiological and ychological experiments on vision, to provide short flashes light of controlled duration. In some circumstances this esents a problem for which there is no ready solution. A ndulum shutter is at best clumsy, photographic shutters sometimes employed, but even the most expensive are t sufficiently accurate for any but the crudest work. Not ly are photographic shutters subject to a high degree of riance, but they tend to become faster with repeated posures, introducing systematic changes very difficult to rrect, and they are affected by temperature changes which particularly serious when used in conjunction with a pro- tion system where the heat may be considerable. In actice, flashes as short as 1 ms are often required for visual earch.

It is sometimes possible to avoid the use of shutters alto- ther by switching the light source itself, but this is not nerally permissible. It is usually unsatisfactory where the ht source is a filament lamp because of the low rate of rise d fall in intensity when switched, though filament lamps often the most convenient source in other respects. here the beam is split, it may be necessary to have a shutter the system to affect only one beam.

DESIGN

The shutter utilizes the well-known principle of the ating disk with a peripheral sector. The disk is arranged interrupt the light beam except for the sector at its periphery. achieve as nearly as possible a square-wave flash the gular velocity of the sector should be high. This is particularly important if the optical aperture is large where the utter cuts the beam. In practice a disk diameter of about inches is convenient.

The problem is to adapt this familiar arrangement to ovide single flashes at the will of the operator. This is complished here with a solenoid-operated "masking" utter arranged to interrupt the beam except when a flash required. It is so arranged that the masking shutter starts open immediately *after* the sector in the continuously ating disk has passed the light beam, which is therefore cluded by the disk for the maximum time before the sector urns. The masking shutter thus has the maximum possible ne to open before the sector reaches the beam, which now ults in a flash. The masking shutter then starts to close mediately the sector has passed the beam—i.e. imme- tely after the flash—and so it has also the maximum ssible time to close before the sector again returns to the am. Thus the flash duration is entirely determined by the k with its sector, and the masking shutter can be com- ratively crude. In fact, it is simply an aluminium flap erated by a solenoid and returned with a spring. The only oblem is to synchronize this solenoid with the disk so at when a flash is required it is always energized and de- ergized immediately after the sector has left the beam. A ssible disadvantage of the system is that there is a slight riable delay between the operation of the shutter and the ulting flash, but this does not generally matter, especially it is possible to record the time interval between the flash and the result (such as the observer's response) simply by adding a contact for the time recorder to the shaft of the disk.

The design problem is to synchronize the masking shutter with the disk so that one, and only one, complete flash is produced whenever the key is closed. It is most important that flashes are never cut short by the masking shutter failing completely to open or close in time for the sector's arrival at the beam.

THE SYNCHRONIZING CIRCUIT

When the key is closed, no circuit is completed until the commutator on the disk's drive shaft is "made." The synchronizing pulse from the commutator energizes *RL*1 which holds, the holding circuit being through the micro-switch operated mechanically by the masking shutter, and a "break" contact on *RL*2 (see figure). The commutator is arranged to give a synchronizing pulse of just sufficient length to close *RL*2 when the disk is rotating at its maximum speed. The closing of *RL*1 energizes the solenoid, raising the masking shutter. While the masking shutter is opening, the sector is approaching the optical path: the solenoid remains energized until the commutator closes again, giving a second synchronizing pulse. But this time the micro-switch has been changed over by the mechanical movement of the masking shutter: the result is that the second synchronizing pulse energizes *RL*2, which holds. The closing of *RL*2 prevents the solenoid from being energized by further pulses, although the key may be held down. For high disk speeds this is an essential precaution against unwanted multiple flashes. When the key is raised, the holding circuit to *RL*2 is broken, and so the circuit re-sets.

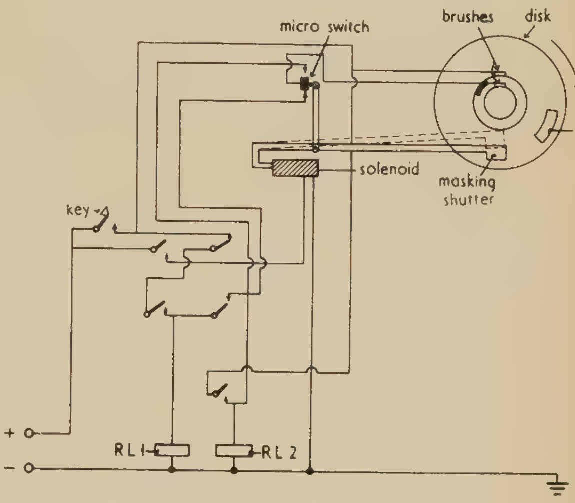


Diagram of arrangement for rotary disk optical shutter

There is a complication in that the key might be closed while the commutator is closed. When this occurs the synchronizing pulse will be cut short and may not be long enough to close *RL*1. When this occurs, the circuit remains inoperative until the next synchronizing pulse arrives, and this time it must be a complete pulse. It is important to note that the masking shutter has to be fully open before the sector reaches the optical path even when the beginning of the synchronizing pulse is lost, provided there is sufficient to close *RL*1. Thus the synchronizing should be set from the *end* of the pulse. Since there is some delay in the closing of *RL*1, the commutator should be advanced slightly.

THE DISK DRIVE

A number of methods have been tried for driving the disk. Where it is necessary to vary its speed a Velodyne might be used, or a mains or crystal driven synchronous motor driving through a ball-and-disk integrator is suitable.

For the production of 1 ms flashes, a shaft speed of 3000 r.p.m. is convenient. This flash duration will then be obtained with a 17° sector, providing the masking shutter can open fully within about 0·03 s and close within the same time. Shorter flashes may be obtained by reducing the sector angle, though its width should be several times the width of the light beam if reasonably "square" flashes are to be obtained.

Very long flashes may, of course, be obtained by stopping the disk so that light passes through the sector, and using the masking shutter as a simple solenoid-operated shutter. The lower limit to the obtainable flash lengths is set by the masking shutter. It should be possible to produce very short flashes by introducing a second disk, also with a sector, geared to the first so that the two sectors coincide, say, every ten revolutions of the first "master" disk. The minimum flash length would then be reduced by a factor of ten.

Use of coarse gratings to find the refractive index of materials

By Gopala Menon Sreekantath, M.A., and C. A. Verghese, M.Sc., University College, Travancore University, Trivandrum, India

[*Note received* 17 *June*, 1957]

A novel and accurate method of finding the refractive index of materials in the form of plates is described below. The only equipment required is a pair of exactly similar coarse transmission gratings—about 150 to 200 lines/cm—a spectrometer and sodium light.

The gratings are mounted between the telescope and collimator, one near the telescope and the other near the collimator on sliding supports fitted to them. The planes of the gratings are set normal to the incident beam of parallel rays and the lines of the gratings parallel to the slit. Lau has shown experimentally and theoretically that a set of clea equidistant interference bands will appear in the field of vie of a telescope directed to view the slit, when the distanc between the gratings is a multiple of Δ^2/λ where Δ is th width of the grating element and λ the wavelength of ligh If a wide slit is used these bands appear against the back ground of the various orders of diffracted images of the sli the bands are quite dark and clear when the distance betwee the gratings is an odd multiple of Δ^2/λ, and by adjusting th distance between the gratings such a system of dark bands obtained.

The transparent plate of thickness t is mounted on th prism table and levelled so that its plane is vertical an normal to the beam of light. The crosswire of the telescop is set on the dark band at the centre of the band system an the reading of the prism table relative to the fixed telescop is taken. Now if the prism table is turned in one directio say clockwise, the bands will move across the crosswire o by one. The reading of the prism table is noted as eac band comes up to the crosswire, and the observations a repeated, turning the table in the opposite direction.

It can be proved that a shift of one band takes place the parallel rays incident on the plate undergo a lateral di placement Δ when emerging from the plate. Now th lateral displacement of the emerging pencil of rays is rela to the angle of incidence i by the equation

$$s = r\Delta = t \sin i\left[1 - \sqrt{\left(\frac{1 - \sin^2 i}{\mu^2 - \sin^2 i}\right)}\right]$$

where r is the number of bands getting displaced. The val of i is obtained from the readings taken. Typical observati using a glass plate are given in the table and the refracti index μ is calculated. The accuracy of the value of μ depen on the value of i, the greater the value of i, the smaller is th error. Hence exact value of μ is given by the angles incidence for which r is large.

The method is equally applicable to a liquid in an optic cell.

Change in the band shift with angle of incidence

Shift No. of bands r	*Displacement* $r\Delta$	*Reading clockwise*	*Difference*	*Reading anti-clockwise*	*Difference*	*Mean difference* (i)	μ
0	0	45° 30′		45° 30′			
8	8 Δ	22° 48′	22° 42′	68° 8′	22° 38′	22° 40′	1·552
12	12 Δ	13° 16′	32° 14′	77° 41′	32° 11′	32° 12′ 30″	1·550
16	16 Δ	5° 9′	40° 21′	85° 51′	40° 21′	40° 21′	1·552

Thickness of plate = 0·382 cm, *width of grating element* = 0·0071 cm

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* Lau, E. *Ann. Phys.* [*Leipzig*], **2,** p. 417 (1948).

New instruments, materials and tools

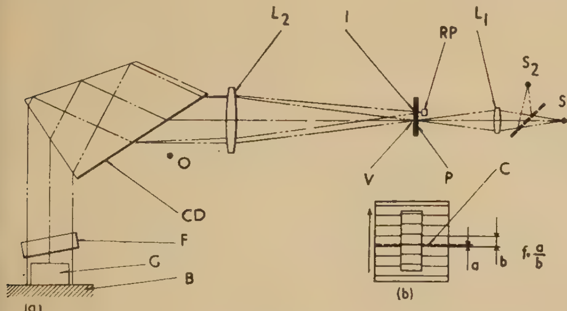
The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved products. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

Interferometer for slip gauge measurement. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

The N.P.L. model B gauge interferometer is now being manufactured by this firm for routine measurements of length in standards rooms and industrial laboratories, the instrument having been structurally redesigned on more robust lines than the prototype. The purpose of the interferometer is to measure slip or block gauges up to 4 in. length, and one of the important features is that the steel work-platen on which the gauges are wrung will accommodate up to 18 gauges so that they can be measured rapidly one after the other, the platen then being removed and replaced by another platen already loaded. In this way a complete eighty-one piece set can be measured in a comparatively short time. No special skill is required and ordinary inspection or laboratory staff can quickly be trained for the work.

The instrument also enables the surface of block gauges to be examined for flatness and parallelism, and it can be used for comparing the lengths of nominally equal slip gauges, or for determining the difference between two gauges of substantially different lengths.

The optical system is illustrated in Fig. 1(*a*), and consists of two light sources S^1 and $S,^2$ which can be selected as required, condenser lens L^1, focusing the light on to an aperture V which is set at the focal distance of the achromatic objective L^2 so that light emerges from the objective as a parallel beam and is transmitted to the constant deviation dispersing prism CD. This prism can be rotated about an axis o by a micrometer screw with a drum on which are engraved the setting positions for selecting the required wavelength.



Slip gauge interferometer, (*a*) optical system, (*b*) field of view

The light then passes on to an optical flat F whose lower face is coated with a layer of bismuth oxide which allows of partial transmission and partial reflexion of the light. Transmitted light passes on to the steel platen B and the end face of the gauge to be measured G, which is wrung on the platen; the light is then reflected back in the reverse direction and is directed so that on arriving at plate P the light emerges from an exit aperture I below the entrance aperture where it is turned by mirrors RP into a viewing telescope inclined at a convenient angle for observation. By slightly inclining the optical flat in relation to the steel platen B parallel interference fringes are formed across the surface of the platen, and also across the face of the gauge as shown in Fig. 1(*b*). In general the fringes on the platen will be displaced from those across the gauge face and in measuring the length of a gauge it is only necessary to determine the fringe fraction, as it is called; that is to estimate the fringe displacement in terms of the fringe spacing. Thus, if a is the displacement, b the fringes spacing, the fringe fraction $f = a/b$. Very little experience is required to estimate this fraction to 1/10 of a fringe spacing, or better. The adjustable crosswire C, Fig. 2, may be used as an aid to estimation. The fraction is estimated in each case for monochromatic light of four wavelengths, and this can be done in less than a minute. With this information and with the aid of a slide-rule and tables provided, it is claimed that the length of the gauge can be determined to better than 0·000001 in. (0.000025 mm).

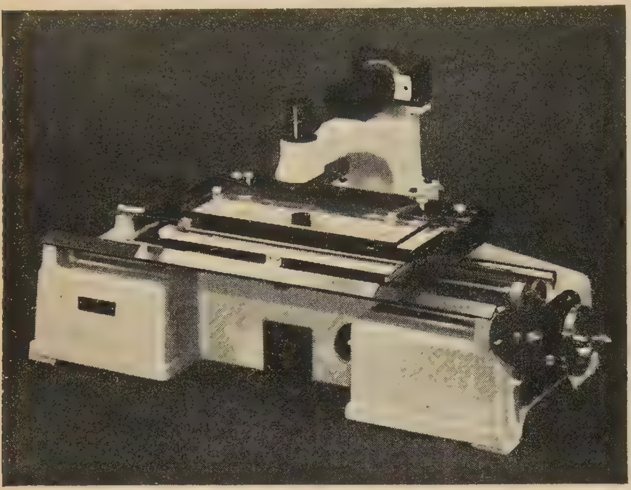
The case enclosing the steel platen, optical flat and wavelength prism is double-walled with heat insulating material between the walls. The door is of Perspex, also with double walls, but in this case not filled so as to provide a window for observation of the gauges within the measuring chamber. The equipment includes a mercury-198 and a cadmium lamp, together with a supply unit for a.c. current with meters to regulate the current supply to each lamp. The mercury-198 lamp requires a water supply. A slide-rule for four radiations of mercury-198 and the cadmium red radiation, with tables and full instructions, are included. An additional slide-rule for four cadmium radiations only is available.

X-ray microphotometers. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

The Hilger X-ray microphotometer is designed for measuring the intensities and spacings of diffraction lines on photographic film. Its scanning distance and range of sensitivity make it suitable for measuring Debye-Scherrer powder patterns, and it has linear scales for determining Bragg angles. The instrument can be supplied as a hand-driven non-recording microphotometer or as a motor-driven recording microphotometer. The stage traverses a total distance of approximately 270 mm, which is adequate for determining line intensities from patterns produced in cylindrical powder cameras. It is driven by a synchronous motor with two speeds: 0·9 mm/min and 2·25 mm/min. The faster of these is advantageous when the pattern has widely separated diffraction lines. The slower is essential for determining line-profiles accurately. Control of sensitivity is provided so that the instrument will measure satisfactorily the wide range of line-intensities characteristic of X-ray diffraction patterns. Diffraction patterns can be recorded by using the microphotometer in conjunction with a strip-chart recorder.

The stage can be moved by hand to any desired position. A hand-wheel is provided for adjusting the film or for driving the non-recording model of the instrument. A notched wheel allows discontinuous scanning by hand in steps of one-twentieth of a millimetre; line-profiles can therefore be plotted with the non-recording instrument.

The optical system accords with normal practice. A reduced image of the filament of the lamp is focused on the film, an image of which is projected on the whitened jaws of the slit before the photomultiplier. The width of the slit is controlled by a knurled ring divided at intervals of 0·02 mm; its height can be reduced by means of a fish-tail diaphragm to any amount from a maximum of 20 mm. The magnification of the film at the slit is about three times. A sphero-cylindrical "viewing lens" can be moved into the lightpath to flood a small area of the film with light, so that an image of the area is thrown on the slit-jaw screen to simplify adjustment of any line into the measuring position. The output from the photomultiplier is fed to the pen recorder through a d.c. amplifier in a unit also embodying a power supply. The film is held on the stage between two glass plates. The stage runs on guides and can be moved by hand to any position over a total travel of approximately 270 mm. With the drive engaged, the stage can be traversed smoothly, either by hand or by motor, through a distance of 152 mm. The motor has two speeds: 0·9 and 2·25 mm/min. The driving screw is fitted with a micrometer drum reading to 0·01 mm, and a millimetre scale in front of the stage can be read by vernier to 0·1 mm.



X-ray microphotometer

Frequency and amplitude modulated signal generator. Marconi Instruments Ltd., St. Albans, Hertfordshire.

The type TF1066/1 generator has a carrier frequency range extending from 10 to 470 Mc/s, and the output can be set at any level between 0·2 μV and 200 mV. Frequency modulation is monitored and variable up to a maximum of 100 kc/s deviation. Amplitude modulation is monitored and variable to any depth up to at least 40%. Both stepped and continuous controls are provided for incremental tuning. The stepped control provides fixed positive or negative shifts of 5, 10 and 15 kc/s; the advantage of this feature is the ease with which rapid checks of receiver bandwidth can be made. Precise adjustment of carrier frequency is facilitated by the inclusion of a fine tuning control covering a range of about 25 kc/s. The frequency stability is stated to be better than 0·0025% in a 10 min period, corresponding to a drift of less than 800 c/s per min at 300 Mc/s.

Low frequency phase-meter. Muirhead and Co. Ltd., Beckenham, Kent.

The D-729-BM phase-meter is designed to measure the phase difference between two alternating potentials in the frequency range 0·5 c/s to 10 kc/s. The principle of the instrument i that the two potentials are separately adjusted to a pre determined value and their vector sum is then recorded; thi is a function of the phase difference, so that the meter ca be scaled to read phase difference directly. If each potentia separately is set to a value v_0 and θ is the phase angle betwee them, the vector sum is $2v_0 \cos \frac{1}{2}\theta$. If v_0 corresponds to $1/\surd$ of full-scale deflexion, a vector sum of full scale is given fo phase angles of 90 or 270°. If θ lies in the 1st or 4th quadrant the deflexion will exceed full scale. It is then necessary t switch in a sign reversing stage into the reference channe so that the meter reads $(\pi - \theta)$. The position of the reversin switch needed to bring the pointer on to the scale therefor discriminates between phases lying in the 1st or 4th quadrant on the one hand or the 2nd or 3rd quadrants on the othe To resolve the remaining ambiguity, a phase retarding net work is switched into one or other channel and it is note whether the vector sum increases or decreases.

Each input channel comprises a three-stage amplifier a attenuator with a range of 70 db in steps of 1 db. The out puts from the two channels are applied separately, or adde together, to an output amplifier. The latter can either b switched direct to the built-in meter, or connected *via* a external amplifier or filter circuits. The instrument accept input voltages from 10 mV (5 mV at frequencies above 1 c/s to 20 V, the input impedance being 30 MΩ shunted b 15 pF. An accuracy of 1° is claimed in phase angle measure ments.

Portable mass spectrometer. Consolidated Electrodynami Corporation, 300 North Sierra Madre Villa, Pasade California, U.S.A.

The type 21-611 mass spectrometer is intended as an accurat but inexpensive small-size model weighing only 115 lb. Th mass range covered is from 2 to 80 and the resolving powe is stated to be adequate for the separation of adjacent peak up to about mass 35. The mass scanning is so arranged tha mass numbers appear linearly with time on a large, moto driven dial, making mass marking unnecessary. The ma numbers appear equally spaced on a fixed time base. A manual over-ride on the motor drive permits the operator t turn quickly to any mass number of interest or to start an stop the automatic scan at any desired point. A metal rota valve is employed for introducing the sample, and it is state that traps and separate pumping units for the inlet syste are not needed. It is claimed that the equipment will detec gaseous impurities present to the extent of a few parts pe million.

Low frequency oscilloscope "servoscope". A. E. Cawkel 6–8 Victory Arcade, The Broadway, Southall.

This oscilloscope is specially designed for the study of lo frequency phenomena. It employs a 20th Century Electroni precision 6 in. double gun tube having a long-persistenc phosphor with blue flash and orange afterglow. The time base has a frequency range from 0·01 c/s to 10 kc/s and i fitted with coarse and fine controls calibrated to an accurac of 5%. There is also available for voltage and time measure ment a square-wave generator with a number of accurate calibrated voltage outputs and frequencies of 1, 10, 100 o 1000 c/s. The differentiated output may be switched to th cathode-ray tube grid to produce brightness modulation tim marks. A further refinement is an r.f. oscillator beam brighten ing circuit which serves to switch on the beam (*a*) by a external switch, (*b*) by an external signal of 60 V or (*c*) b e time-base sweep (fly-back suppression) on the lower equency ranges. On the highest ranges, flyback is directly ppressed from the time-base wave-form. The instrument ntains an X-amplifier and two identical Y-amplifiers. The tter cover the frequency range zero to 20 kc/s and are niform to 1 dB. The d.c. drift is stated to be less than mV/h, and the noise and hum with open-circuit input is less an 50 μV. At maximum gain, the sensitivity is 3·5 mV/cm. he X and Y deflector plates of both guns of the cathode-ray be are externally accessible.

lagslip synchros for special purposes. Muirhead and Co. Ltd., Beckenham, Kent.

common type of synchro contains three equally spaced ator windings and a rotor winding. It is obvious that if the tor is energized with d.c., the device will function as a three- ase alternator. Since the synchro is constructed to close lerances, the three-phase voltages developed in this way ill have very good wave-form and will be accurately separated phase. Clearly the wound rotor energized by d.c. can be placed by a permanent magnet, and a three-phase Magslip ternator of this type is available under the designation -28–C/1. A Magslip element having only two stator indings may, of course, be used as a two-phase alternator; ch a machine, with a permanent magnet rotor, is available ıder the designation E–28–A/1.

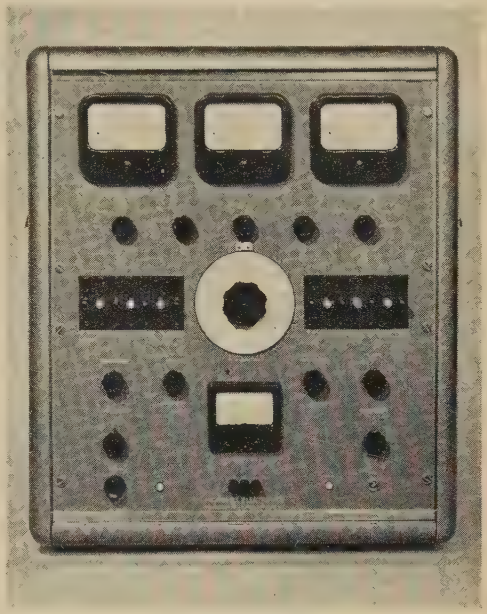
Another specialized Magslip is known as the Monodiff pe E–82–B/1. It is intended for comparing the relative ıases of two three-phase supplies. This instrument has two parate three-phase stator windings, corresponding coils of e two sets being co-axial. The rotor is a simple laminated ft iron structure mounted on a spindle. The two stator indings are connected to the two supplies in such a way that ıe supply tends to produce a magnetic field rotating in a ockwise direction, and the other a field rotating anti- ockwise. The resultant is an alternating field whose direc- on depends on the phase relation between the two supplies. ıe rotor alines itself along the axis of this resultant field, bject of course to an ambiguity of 180°. By using this agslip in conjunction with two of the alternators described ove, it is obvious that the phase difference, or difference in eed, of two rotating shafts can be measured.

scilloscope beam switch. Furzehill Laboratories Ltd., Watford, Hertfordshire.

ıe beam switch type S.500 has been designed to provide two dependent traces on an existing single-beam oscilloscope r on the individual channels of a double-beam instrument). ıe device has a wide band-width from 10 c/s to 5 Mc/s so to retain the maximum usefulness from the existing flexion amplifier in most oscilloscopes. Since the phase rors of the amplifiers in the instrument are small, it can be ed for phase comparisons. The device incorporates two dependent cathode-follower input stages, the outputs of hich are switched electronically to a cathode-follower output age which feeds the normal input to the oscilloscope. The itching frequency is asynchronous, and is variable over the nge 350 to 3500 c/s to suit the wave-forms being studied. ıe gain and d.c. level of the amplifiers are independently riable so that both amplitude and position of the two traces n be separately adjusted. A synchronizing signal can be ken with either polarity from either output. Each amplifier s a maximum gain of 2, an input impedance of 10 MΩ in unt with 10 pF and a maximum input of 140 V peak-to- ak. The switch-over time is 5 μs.

Transistor measuring set. Microcell Ltd., Imperial Buildings, 56 Kingsway, London, W.C.2.

The transistor measuring set type 107, shown in the figure, has been developed as a laboratory instrument capable of giving full information on the characteristics of *pnp* and *npn* transistors. Collector and base currents are separately metered and continuously variable over a wide range. Small signal measurements are made at 1 kc/s and include h, T network, open and closed circuit parameters. Circuit configurations employ either a common emitter or common base. Most measurements are simply direct readings on a single calibrated dial. Completely matched pairs of transistors can readily be selected with the aid of this instrument.



Type 107 set for measuring the characteristics of *pnp* and *npn* transistors

Standard signal generator. Airmec Ltd., High Wycombe, Buckinghamshire.

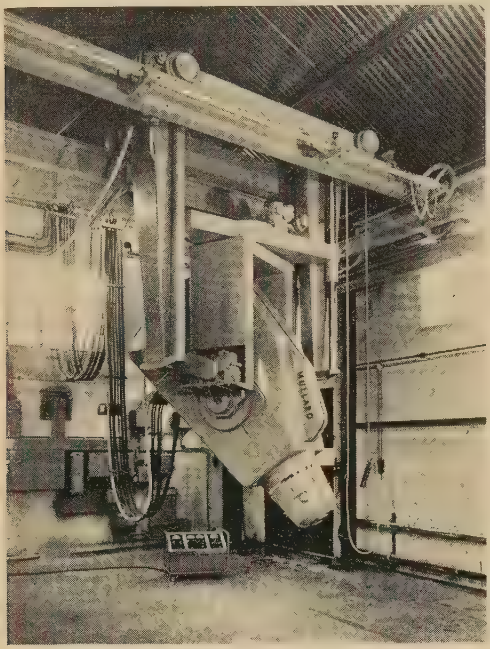
The type 201 signal generator provides a stabilized output from 30 kc/s to 30 Mc/s in seven ranges. It incorporates a film scale giving an actual scale length on each range of 48 in., together with an additional vernier scale giving an effective scale length of 260 in. on each range. A crystal calibrator is included to enable any desired frequency to be set to an accuracy of about 5 parts in 10^5. The oscillator and buffer stages are fed with stabilized h.t. and are temperature compensated. It is stated that this results in a frequency drift of less than 5 parts in 10^5 in 5 min. A mains voltage change of 10% results in a change of less than 1 part in 10^4 in the frequency.

The output signal is stabilized by an amplified automatic gain control system, and remains constant to within $\pm 0\cdot 5$ dB over the complete frequency range with a harmonic distortion at all frequencies of less than 1%. A special attenuator circuit gives continuously variable attenuation over a range of 120 dB with an output impedance of 75 Ω under all conditions. The normal maximum output is 1 V from the 75 Ω source, but this can be doubled in the absence of modulation. A high impedance output socket is provided giving a 5 V signal.

Internal modulation at 1000 c/s is provided and the spurious frequency modulation occurring with amplitude modulation is usually less than 200 c/s. To achieve a pure modulated envelope, negative feedback is applied from the demodulated carrier to the modulation input. The negative feedback voltage is provided by a demodulated audio signal taken from the anode of the automatic gain control diode. This signal is fed in series with the modulation input through a phase-inverting valve so that the feedback and modulation voltages are in anti-phase.

Linear accelerator. Mullard Ltd., Mullard House, Torrington Place, London, W.C.1.

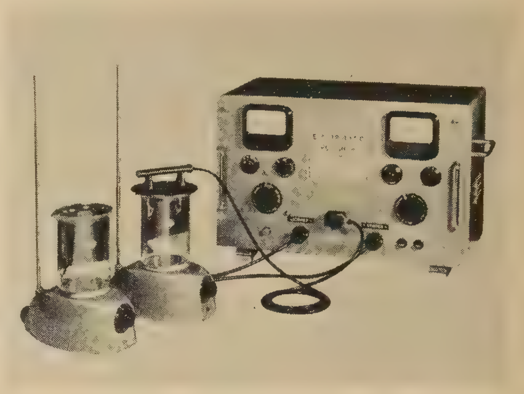
A 5 MeV linear accelerator has been designed for industrial radiography. The advantage claimed for a linear accelerator for this purpose is that it produces a larger X-ray output than a van der Graaf generator, resonant transformer or cascade generator of comparable size. It is also claimed that the machine is more effective than a millicurie ^{60}Co source. The X-ray output is stated to be 500 r/min at 1 m, making it possible to obtain a radiograph of a 10 in. steel specimen in $\frac{1}{2}$ h. In spite of the large output, the diameter of the focal spot on the target is only 2 mm. It is stated that the polar diagram of the output is flatter than usual because of a special magnetic focusing device associated with the X-ray head.



Linear accelerator for radiography. The overhead rail permits longitudinal and transverse movement over the room. In addition, the whole unit can be tilted from vertical to horizontal, turned laterally through 180° and raised or lowered 8 ft

Electrolytic polishing equipment. Nash and Thompson Ltd., Oakcroft Road, Chessington, Surrey.

This instrument consists of a control cabinet and magnetic stirrer assembly. The cabinet contains the power pack which can deliver up to 5 A at 85 V smoothed d.c., coarse and fine voltage controls and a multi-range ammeter and voltmeter. Provision is made for connecting one or two magnetic stirrers into the front of the cabinet, and speed of stirring is regulate by means of a control knob mounted in the base of each Each stirrer accepts a standard 1 l. beaker, one containin the electrolyte and the other water for washing the specime immediately after polishing. On the top rim of the electr lytic beaker is fitted a moulded polythene cap containing th two electrodes in the form of quick-release clips. Thi electrode cap is connected to the cabinet by a flexible cab and can very quickly be transferred to the water beaker a the end of the polishing cycle, thus minimizing the possibili of unwanted chemical etching or staining of the specim It is possible to replace the electrolyte beaker with anothe very quickly, so that a number of different metals can b polished by several operators using the instrument in quic succession.



Electrolytic polishing equipment

Grinding and polishing machine. R. and J. Beck Ltd., 69/7 Mortimer Street, London, W.1.

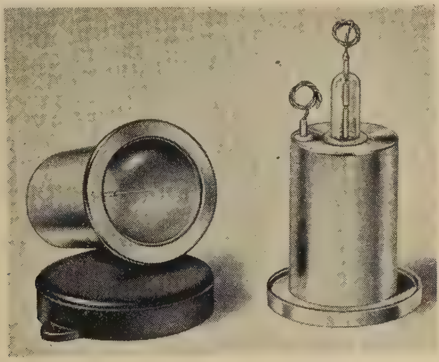
This equipment has been developed for the preparation metallurgical specimens for microscopy. While compa

Automatic grinding and polishing machine with multiple fixed chuck ough to be used on a bench, the external dimensions being × 15 × 8 in., it is robust and capable of either hand or tomatic grinding and polishing. All vulnerable metal surces are either of stainless steel or are hard stove-enamelled d considerable thought has been given to the general design facilitate cleaning. The rubberoid material Gaco has en used extensively in the equipment because it is cometely impervious to all oils and spirits and will not perish the same way as rubber, although physically it has very milar properties.

Three forms of specimen holder are available, the simplest ing a single pin which drops into a hole cast into the ecimen blank. This enables the specimen to find its own vel and results in quicker polishing but in extreme contions can result in a slight rounding of the specimen edge. he rounding can be obviated by using the single fixed chuck, it since this prevents the specimen from being self-levelling, nger periods of grinding may be required. Also, for the ked chuck, the specimen must be set in a 25 mm diameter ank, whereas the single pin imposes no restriction on the ecimen size. Where larger numbers of specimens are to be repared, a three specimen chuck is used which accommodates ree blanks 25 mm in diameter. This chuck enables identical olishes to be achieved on three similar specimens which n then be independently etched.

nd-window counter. 20th Century Electronics Ltd., King Henry's Drive, New Addington, Croydon, Surrey.

he EW2A counter has been developed for two particular oplications. The first is the assay of samples of low energy emitters. For this purpose, the employment of mica end indows of between 1 and 2·5 mg/cm^2 thickness permits the ficient use of the counters with β radiation as low as 60 keV. he second application is the measurement of low activity imples of β emitters. For this reason, materials and design ave been chosen to reduce the background and to improve e counting stability.



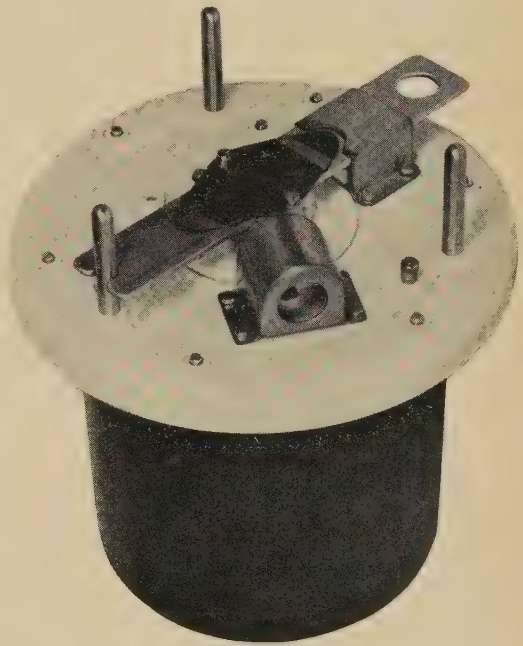
Mica end window counter with organic quenching

.c. amplifier. Automatic Coil Winder and Electrical Equipment Co. Ltd., Avocet House, 92–96 Vauxhall Bridge Road, London, S.W.1.

he d.c. amplifier type 1388A has been primarily designed for e measurement of ionization currents. The current to be easured develops a voltage across a high resistance. This oltage is amplified and fed to an indicating meter. Negative edback is employed so that the readings are substantially dependent of the amplifier gain. A control is fitted to vary e time constant of the input stage. Seven ranges are provided, these being selected by means of a switch on the panel. The instrument will measure from 10^{-6} to 10^{-12} A at a full scale sensitivity of 10 V. It is stated that the accuracy of current measurement is 3% of full scale deflexion. For operating a current recorder, a cathode follower output stage is provided. This will deliver up to 100 mV with an output resistance of 100 Ω. A change of 10% in the mains voltage is stated to produce a zero error of less than 10 mV; the long term stability is better than 25 mV over several weeks' running. A useful feature is the provision of a potential of 100 V for polarizing an ionization chamber.

Combined β and γ ionization chamber. General Radiological Ltd., 15–18 Clipstone Street, Great Portland Street, London, W.1.

The type 1383A chamber shown in the figure is a combination of a re-entrant cylindrical chamber for the measurement of γ-ray emitting isotopes and a parallel-plate type of chamber for measuring β-ray emitters. The γ-ray chamber consists essentially of three concentric brass cylinders of radii approximately 3·6, 6 and 8 cm respectively, and lengths 13, 16 and 18 cm, the intermediate cylinder being the collecting electrode. The β-ray chamber occupies the lower part of this cylinder, the ionized volume being between the dome-shaped electrode and the bottom plate. The β-rays enter the chamber through a graphited plastic window of thickness 0·001 in. and diameter 4 cm. The source (1 ml. of liquid in an alkathene dish) is mounted on a slide, its surface being about 2 cm below the window. The total ionized volume of the chamber is about 3 l.; the volume of the β-ray chamber is about 0·15 l. The electrical capacity is about 25 cm. The γ-ray chamber has a sensitivity of about $4{\cdot}4 \times 10^{-11}$ A/mg when tested with 250 μg of radium. The β-ray chamber when tested with a liquid containing a few μc/ml. of ^{32}P has a sensitivity of about $3{\cdot}5 \times 10^{-10}$ A/ml. The background current is about 10^{-14} A.



Combined β and γ ionization chamber for the maintenance of standards of radioactive nuclides

New books

Pressure measurement in vacuum systems. By J. H. Leck. (London: The Institute of Physics, 1957.) Pp. 144. Price 30*s*.

Mr. Leck's book will prove a valuable addition to those already published in the "Physics in Industry" series. It meets the need for a comprehensive treatment of the subject of pressure measurement in vacuum systems and provides a complete guide to the choice of suitable pressure gauges and the correct interpretations of their readings.

Five types of pressure gauge are considered and the material is presented in six independent chapters the titles of which are: Mechanical manometers; Thermal conductivity gauges; Ionization gauges; The Knudsen radiometer gauge; Surface reaction techniques; Gauge calibration. Practical considerations are covered by the inclusion of numerous examples of design taken from literature; gauges of primarily historic interest such as the viscosity manometer have not been considered.

The book contains nearly one hundred illustrations together with a subject and name index. A comprehensive list of references is also included.

R. G. A.

Electronic components handbook. Edited by Keith Henney and Craig Walsh. (New York: McGraw-Hill Book Co. Inc.; London: McGraw-Hill Publishing Co. Ltd., 1957.) Pp. 244. Price 67*s*. 6*d*.

The purpose of this book is to give information on four of the principle electronic component parts—resistors, capacitors, relays and switches. It is essentially written around American military specifications for these components and, in fact, summarizes the relevant specifications.

There is, however, much more information given which will be found generally useful as it is descriptive of the various types of device in each category without particular reference to military equipment. The pattern for each section is first a general treatment, followed by specific information applying to the several individual types. In addition each section is well supplemented by general references to technical journals or books.

A. J. Maddock

Photosensitors. By W. Summer. (London: Chapman and Hall Ltd., 1957.) Pp. xvi + 675. Price 105*s*.

This book appears to be addressed mainly to the factory engineer. The first half discusses the physical basis of "photosensitors" (photoelectric elements) and their associated circuits and optical methods. Some of these chapters are useful, others less so. For example, on colour an objective treatment in terms of spectral energy distribution is required: instead there is a chapter largely concerned with subjective sensations. Unfortunately there are also many examples of careless writing and presentation. Thus the author is unreliable on light units, symbols and dimensions; spurious accuracy is seen in tables giving electron-volt equivalents of wavelengths to 6 significant figures, and quantum efficiencies to 8 or 9; sources *B* and *C* are said to have filaments operating at 4800° and 6500° K; the ampere is said to be defined as the flow of $6{\cdot}242 \times 10^{18}$ electrons per second past a given point; and throughout the book numerous errors have been found, some trivial, some obvious, some serious. Many seem to arise from the uncritical compilation of material from every available source, including commercial literature.

In the second half of the book the author describes a great number of applications of photoelectric devices to all kinds of processes in measurement and counting, in industrial safety measures, inspection and control. A chapter on luminescenc occurs in this section. It begins with our old friend Casciarola continues with tables of phosphor emission data, and detai a number of applications, some of them very inadequately.

The most serious limitation of the book is its lack reference to recent work, particularly on photoelectric sur faces, scintillation counting, pick-up tubes and photo conductors. This is due to the fact that the bibliograph (2648 references including about 700 patents) is largely date 1936–1946, with a few articles up to 1952 only. The boo is well printed with many clear diagrams, but the half-ton illustrations are not so successful. Though it contains muc interesting material, this book cannot be recommended a an accurate or up-to-date survey of the subject.

S. T. Henderson

Manuel de photographie scientifique. (Sciences physiques biologiques.) By Gerard de Vaucouleurs, Jea Dragesco and Pierre Selme. (Paris: Editions de Revue D'Optique, 1957.) Pp. 391. Price 3000 *f*.

Among the many books which describe the technique photography, ranging from elementary instruction books amateurs to those which go deeply into scientific analysis the behaviour of photographic materials and apparatus, th handbook has the particular objective of catering for tho who apply photography to the practice of science. The of photography in scientific and technical work is wide-sprea and of its value there is no question. Progress would hav been, and still be, very much slower, and some branches science almost non-existent, without photography. Th operations required to obtain a photograph are not at a difficult. Nevertheless, only good luck will produce a goo photograph unless the photographer really understands th particular technique which may be required. This boo would help him.

It describes the properties of photographic materials an accessory apparatus, namely camera lenses, cameras, micro scopes, light sources, filters and exposure meters. Th next step in the treatment is a description of the processin required, starting with a discussion of the kind of laborator required for photography and followed by descriptions development, fixing, washing and drying, intensification an reduction and the production of positive prints. The thir part deals with the special techniques of colour photograph photography in the infra-red and ultra-violet, with X-ray and γ-rays, the recording of electrons (as in the electro microscope), and the use of special emulsions for recordin particle tracks. The scientific applications which follo embrace position and intensity measurements, photomicro graphy and cine-photomicrography, macro-photograph (defined as same-size or slightly enlarged reproductio document copying, photography of plants and animals, an landscape (and underwater) photography (for geological an ecological records). The fifth part of the book is a ve useful collection of data, in the main for commerciall available materials and apparatus. The names of the autho may be taken as a guarantee of the soundness of the info mation. The book is easy to read and would be a valuab addition to the library wherever scientific applications a found for photography.

I was surprised to find no reference to astronomical phot graphy (except a plate of a comet indicating the increase contrast attainable by successive printing) in view of th interest of one of the authors in the subject. Perhaps it wa garded as too specialized. Some reference might have een made to stereoscopic photography and, as a whole apter deals with nuclear track photography, also to the chnically interesting problem of Wilson cloud-chamber otography. The section on the methods of development uld well be extended.

There are, of course, a few points which should receive tention in future editions. It is hard to see how varying e aperture of the projector lens of a properly adjusted ondenser enlarger can produce inequalities of illumination the projected image as a result of non-uniformity of bright-ess of the lamp (p. 179 and p. 181). Surely it was starch, ot yeast, which was used in the Lumiere colour materials . 190)? Kodachrome cannot really be said to be grainless . 193). On p. 83 there is misnumbering in the reference to late XXVIII and the date of Michel's book on the theory f the microscope should obviously be 1950 (p. 91).

E. W. H. Selwyn

rogress in semiconductors. Vol. 2. Edited by A. F. Gibson, P. Aigrain and R. E. Burgess. (London: Heywood and Co. Ltd., 1957.) Pp. vii + 280. Price 63*s*.

his second volume should certainly serve to establish the ew series as an important reference source. There is first n authoritative article on the experimental and theoretical spects of semiconductor alloys, including a discussion of ptical and transport properties. This is followed by a seful summary of the work on intermetallic (III–V) com-ounds with an extensive bibliography. The subject of adiation damage in germanium, silicon and indium anti-onide is comprehensively surveyed with special reference to e creation of new energy levels, annealing phenomena, cattering processes and lifetime. The lifetime of free electrons nd holes in solids is also the subject of a special treatment which phosphors and photoconductors are considered ithin the same unifying framework of theoretical models. here is an informative account of the remarkable successes chieved in the production of high quality germanium rystals, including some beautiful plates of etch pits obtained nder various conditions. A general discussion of sub-titutional and interstitial impurities in germanium follows nd a further paper deals with the phenomena observed in emiconductors under high field conditions. This is a wel-ome summary of information which is otherwise scattered ver numerous sources. A chapter of theories of electro-uminescence concludes the volume. It is mostly concerned ith powder phosphors. The book is well produced and can e generally recommended.

H. K. Henisch

merican Institute of Physics Handbook. Edited by Dwight E. Gray. (New York: McGraw-Hill Book Co.; London: McGraw-Hill Publishing Co. Ltd., 1957.) Pp. 1200. Price 112*s*. 6*d*.

his handbook, devoted specifically to physics and sponsored y the American Institute of Physics, is the first in this field o be compiled in America and is notable for the compre-ensive range and detail of information included between its overs. With Dr. Gray, National Science Foundation, as o-ordinating editor and the eight editors responsible for the ain sections into which the handbook is divided for logical resentation of the data, there is an impressive list of 105 pecialist contributors. The sections and the editors are: athematical aids to computation (Dr. Albert A. Bennett); echanics (Dr. R. Bruce Lindsay); acoustics (Dr. Floyd A. irestone); heat (Dr. Mark W. Zemansky); electricity and agnetism (Dr. D. F. Bleil); optics (Dr. Bruce H. Billings); atomic and molecular physics (Dr. G. H. Dieke); and nuclear physics (Dr. F. N. D. Kurie).

Apart from the short section of five pages on mathematical aids to computation, mainly devoted to listing the standard mathematical handbooks of tables available from international sources, the general organization of material in the sections is typified by the following list of contents for acoustics (179 pages): acoustical definitions; letter symbols and conversion factors for acoustical quantities; propagation of sound in fluids; acoustic properties of gases, liquids and solids; properties of transducer materials; frequencies of simple vibrators; musical scales; radiation of sound; architectural acoustics; speech and hearing; classical electro-dynamical analogies; the mobility and classical impedance analogies; and selected references on acoustics. As examples of the tremendous scope of the new handbook the following topics in other sections may be mentioned: geophysical data, including subsections on geodesy, seismology, oceanography and meterology; rheological data; cavitation in flowing liquids; laminar and turbulent flow of gases; shock waves in fluids; properties of paramagnetic salts, with data relating to very low temperatures; high pressure effects on solids and liquids; electric and magnetic properties of the Earth and stars; radiation detection, thermal and quantum; spectroscopic data; radio-astronomy; general atomic constants (as evaluated at Johns Hopkins University in 1954); nuclear reaction cross-sections; fission-product chains and yields; health physics; particle accelerators (with a table of the locations and principal characteristics of operational machines throughout the world); and a catalogue of available information on nuclear reactors.

The sources of information are legion, but among those frequently quoted are the International Critical Tables (1926), the Smithsonian Physical Tables (9th revised edition, 1954) and Circulars and other data published by the National Bureau of Standards. An important key to such a storehouse of knowledge is the index, which in this case runs to 48 pages and appears, on a few spot tests, to fulfil its function reasonably well. The text, tabulated data, diagrams, graphs and charts are well presented and the type, though small, is clear. It is difficult for any single reviewer to criticize comprehensively and to suggest improvements for future editions. The ice point on the thermodynamic temperature scale is given as 273·16° K (instead of 273·15° K) and no mention is made of the new definition of the second (ephemeris time) based on the tropical year 1900·0, but both changes are the result of international decisions made in 1954 or later.

This handbook constitutes an invaluable reference work and is strongly recommended to the attention of all physicists, both pure and applied, as well as engineers.

H. Barrell

Semi-conductors: their theory and practice. By G. Goudet and C. Meuleau; translated by G. King. (London: Macdonald and Evans Ltd., 1957.) Pp. xviii + 316. Price 105*s*.

This book gives a fairly comprehensive account of those aspects of the theory of solids which are related to semiconductors, followed by a general survey of their applications, with special reference to diodes and triodes. The treatment in the first part is quite highly formalized, and is possibly a little out of balance with the later part of the book. Here the preparation of semi-conductor material, the measurement of its relevant physical properties, the preparation of devices, and the physical basis of their performance are all included. There are now so many aspects that, by intent, little more than an introduction is given to some of the more recent or more specialized devices and processes.

There are one or two errors, e.g. the title of section 4.2, p. 217, and in a few places the English of the translation is somewhat stilted, e.g. three times on p. 303. Further, the application of Fermi–Dirac statistics to donor and acceptor levels (p. 95) neglects spin and is not strictly accurate.

On the whole, however, the basic aspects of semi-conductors and their applications are helpfully presented.

D. A. Wright

Applied electrical measurements. By I. R. Kinnard. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall Ltd., 1956.) Pp. xi + 600. Price 120*s*.

This book is "one of a series written by General Electric authors for the advancement of engineering practice." It is very largely a book about electrical instruments, and is divided into two parts. Part I (11 chapters) is concerned with measurements of electrical quantities and Part II (8 chapters) with electrical methods of measuring other physical quantities. The first part deals with measurements of resistance, reactance, power factor and allied quantities, and it includes a chapter on the theory of measurements and one on the functional analysis of measurements. The former is largely a simple account of various systems of units, followed, remarkably enough, by a discussion of damped harmonic motion. The chapter on the analysis of measurements gives an account of a particular scheme of nomenclature for the description of measuring systems. As an aid to succinct description, this is quite good, but to claim, as does the "blurb," that it "aids overall understanding" is extravagant. The other chapters in Part I show a curious unevenness: this may be because the author had the assistance of 14 named contributors but did not exert sufficient editorial pressure. There is, for example, a striking contrast between the excellent chapter on instrument transformers and the almost trivial chapter on resistance, inductance and capacitance. Part I ends with a chapter on telemetering, which gives a general survey of a fairly extensive field.

In Part II, six of the seven chapters are concerned with electrical means for measurements in light, heat, sound, statics and kinetics, on liquids and gases, and the measurement of time. Topics noted include spectrophotometry, temperature measurement, microphones, strain gauges, thickness measurement and frequency measurements. The treatment is generally slight, but this part of the book is a useful catalogue of known and tried methods.

There is an extensive bibliography of nearly 500 references—a list which is sometimes as remarkable for its omissions as for its content. There is, on the average, at least one figure a page: most of the figures are a curious combination of isometric drawings and diagrammatic conventions. For example, a figure bearing the caption "Coil connected to ballistic galvanometer for measurement of flux" has a perspective sketch of a galvanometer movement, with lamp and scale, linked by lines to a sketch of a coil through which dotted lines, representing flux, are passing. Any reade qualified to use the book would hardly need "visual aids" o this scale.

It is difficult to determine the class of reader for whom th book is intended. If indeed the work is purely a referenc book, as the preface suggests, then perhaps this question i answered, but the reviewer is left with the feeling that i would best fulfil this function in a non-electrical *milieu*. Th electrical practitioner will not find sufficient detail to satisf him. The book is excellently produced and printed, but th price is formidable.

N. F. Astbury

Microphotography. Photography at extreme resolution. B G. W. W. Stevens. (London: Chapman and Hall Ltd 1957.) Pp. xvi + 326. Price 50*s*.

Here is a book which is likely to become a classic text i scientific photography. In thirteen chapters and thre appendices the author has assembled, in very readab manner, all that needs to be known about the techniques microphotography. That is to say, the photography macroscopic objects by reduction as opposed to that microscopic objects by enlargement, which is rightly describe as photomicrography. The author, who is well known his work on fine-grained emulsions, opens by tracing t development of the subject from the early work of J. E Dancer of Manchester, who appears to have been the fir to use a microscope in reverse for the purpose of photograph Successive chapters are devoted to choice and processing the sensitive material, to the microscope objective and i fine focusing, and to problems of illumination. A very use chapter discusses anomalous image formation, followed b others on graticules and document copying. The appendi contain processing formulae, details of lens calculations an exposure data respectively, and the text is rounded off wit author and subject indexes. It is well printed and boun and the many illustrations are well reproduced. It is pleasure for once to be able to say that a book is well wo its price; it should find a place on the bookshelf of ever laboratory using the technique.

V. E. Cosslett

British Journal of Applied Physics

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Solid state image amplifiers

By Prof. G. F. J. GARLICK, D.Sc., F.Inst.P., Department of Physics, University of Hull

Recent developments in solid state image devices using photoconductors and electroluminescent phosphors are described. The simplest device uses a thin homogeneous phosphor layer between transparent electrodes while more complex amplifiers use a combination of photoconductor and phosphor layers. By using alternating applied fields, microcrystalline photoconductors and phosphors dispersed in dielectric films may be used. The solid state amplifier offers possibilities for image conversion in the infra-red up to 6 μ, in the ultra-violet and in the X-ray regions.

1. INTRODUCTION

) *Photoelectric image amplifiers*

The photoelectric image amplifier or converter has existed many forms for some years. Basically it consists of a otoelectric cathode deposited on a window in a vacuum velope, and of a fluorescent screen arranged so that photo-ctrons accelerated by a suitably applied electric field tween cathode and screen form an intensified image of the iginal picture or pattern projected on to the photocathode. practice, magnetic or electrostatic electron lenses are used obtain well resolved, intensified images. The usual overall plied potential is of the order of several thousand volts. is easy to see that the acceleration of the photoelectrons oduced by the primary image to energies of several thousand ctron volts provides a power gain in the system and hence age intensification. The choice of photocathode material so provides the possibility of image conversion, that is, sible presentation of infra-red, ultra-violet or X-ray images. practice, the longer wavelength limit is at about 1·2 μ, ile the use of the device in X-ray image intensification is nited by the very thin cathode layer and the low stopping wer for the high energy radiation involved. However, the cuum tube image amplifier or converter has a very high eed of response and the final intensified image can be tained at a high brightness level. From time to time tempts have been made to improve the overall gain. nongst them we may note recent Russian ideas for develop-ent of image tubes, e.g., the provision of several secondary ctron multiplying stages in the image tube giving an ditional gain factor of about 10^6, though with some loss image resolution.(1) Other Russian workers have developed ascade image tube system and have published photographs relativistic particle tracks in luminescent crystals taken by eans of the device.(2)

Solid state processes for image intensification

Two rapidly developing fields of solid state physics have de a new form of image amplifier possible, namely, photo-nductivity and luminescence. Photoconductors, that is, terials showing a fall in resistance (or a.c. impedance) en suitably irradiated, have been developed which have h sensitivity and a variety of spectral responses. In the d of luminescence, phosphors have been produced which ow marked electroluminescence, that is, direct and sustained itation of visible emission by an applied electric field. ce the above phenomena are involved in the operation of st solid state image amplifiers we discuss briefly their evant features.

i) *Photoconductivity.* A survey of knowledge of the enomenon has recently been given elsewhere by the writer(3) and the proceedings of a conference on photoconductivity held in 1954 are now available.(4)

When certain solids are excited by radiation of suitable wavelength, free charge carriers are produced in their bulk and in an applied electric field these will give rise to a measurable current in an external circuit. The carriers have a certain mobility μ and effective free life time τ. They move a distance Δ along the direction of the applied field E where:

$$\Delta = \mu\tau E \tag{1}$$

and is known as the "Schubweg."(5) If $I\eta$ charges are liberated per second per unit volume then the energy transported per second (or the power) is given by

$$W = I\eta eE\Delta = I\eta eE^2\mu\tau \tag{2}$$

where I is the intensity of the incident radiation and η the efficiency of carrier production. To compare the photoconductor with the photoelectric surface in the vacuum tube image converter, Diemer, Klasens and van Santen(6) use the corresponding expression for power transport in the latter which is:

$$W' = I\eta' eV' \tag{3}$$

where η' represents the efficiency of the photocathode and V' the overall tube potential.

By comparison of W and W' we have:

$$W/W' = (\eta/\eta')(\mu\tau E^2/V') \tag{4}$$

They then show that for practical values of the factors involved (using caesium–antimony as photoelectric layer and a cadmium sulphide crystal as photoconductor)

$$W/W' \simeq 10^5 \tag{5}$$

Thus at first sight the photoconductor appears to have a much better power gain over the usual vacuum image tube. However, in the photoconductor the power is only available at low potential, and image brightnesses are much lower in the solid state systems using photoconductors than in the vacuum device. The gain factor in equation (5) mainly results from the large value of the carrier lifetime τ in cadmium sulphide which, under the usual operating conditions, is much larger than the transit time of the carriers between the crystal electrodes, i.e. carrier replenishment occurs each time one carrier reaches an electrode. This large lifetime is, unfortunately, involved in the poor speed of response of the photoconductors of practical interest. The latter usually have appreciable conductivity in the dark at room temperature and this offsets their operating efficiency in the solid state amplifier, as shown later.

The photoconductor has some advantages over the photoelectric surface, particularly with respect to spectral response, thickness and density. Photoconductors are available with spectral response limits of several microns wavelength. High stopping powers for energetic radiation are also available, both by reason of the atomic mass of the constituents and also of the large effective volume.

(ii) *Electroluminescence.* Electroluminescence is shown chiefly by phosphors of the zinc sulphide group prepared in special ways.(7, 8) If an alternating applied voltage is used, then sustained luminescence emission results for all forms of the phosphor layer (single crystals, evaporated layers or microcrystalline powder dispersed in a suitable dielectric). Static fields are only effective for single crystals and, under certain conditions, for evaporated phosphor layers. However, the main characteristics of electroluminescence due to alternating applied fields appear to be independent of the particular form of the phosphor layer.(7) The brightness B of the luminescence emission due to an applied peak voltage $V_0 (V = V_0 \cos \omega t)$ and for an angular field frequency ω is given over a very wide range by:

$$B = B_0 \exp(-A/V_0^{1/2}) \qquad (6)$$

where B_0 and A are constants specific to the given phosphor layer. The possibility of a sensitive control of brightness by relatively small changes in applied voltage is immediately apparent. However, the present power efficiency of the electroluminescence process is rather low (approximately 5 to 10 lm/W) and actual operating brightness levels are low compared with those of a cathode-ray tube or vacuum image tube screen.

It is useful to give here a brief explanation of the electroluminescence process in terms of the usual electronic energy band model for crystalline solids. Fig. 1 shows the energy states for the phosphor crystal or layer and an adjacent metal electrode for an instant in the voltage cycle when the metal has a negative potential, as envisaged by Piper and Williams and others [see review of reference (7)]. The applied field (approximately 10^5 V/cm) produces a sharp potential barrier at the phosphor surface involving fields of about 10^7 V/cm. Carriers can be produced initially in this region by the high field which can activate them from low lying levels in the electrode or in the phosphor into the empty or conduction energy band of the phosphor. They are then accelerated in the high field region and cause liberation of further carriers by a collision process. Subsequent carrier recombination luminescence centres gives the observed emission. In alte nating fields the potential barrier system is created an destroyed at each side of the phosphor during each cycl but after initial excitation an ambient carrier concentratio builds up in the conduction band and especially in shallo trapping states. Much of the temperature and field frequenc dependence of electroluminescence has to do with the trappi processes.(7) Obviously the phenomenon depends on th potential barrier formation and the resulting high field Initially the carriers may be released in the barrier regio by external agents, e.g. light, fast particles or high energ radiation. In the subsequent collision processes th electrons involved will never reach energies of more tha several electron volts and the resulting efficiency of lumine cence excitation is correspondingly low. This is a seriou limitation of electroluminescent light sources and it appea to be fundamental in character, offering little hope improvement.

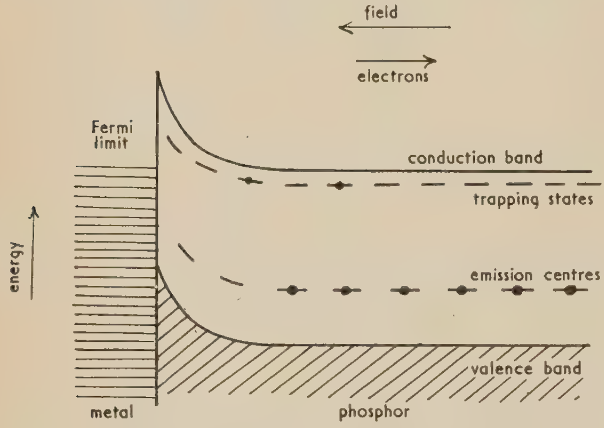


Fig. 1. Electron energy band diagram for contact between an electroluminescent phosphor and a metal electrode (after Piper and Williams)

2. THE SIMPLE ELECTROLUMINESCENT IMAGE AMPLIFIER

The simplest form of solid state image amplifier is that du to Cusano(9) and shown diagrammatically in Fig. 2.

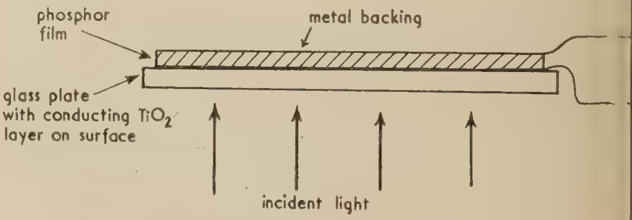


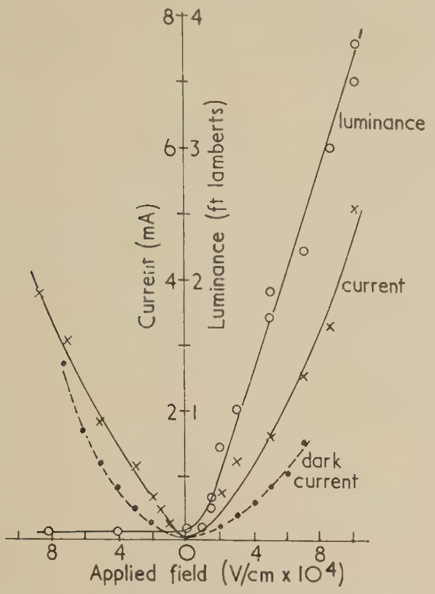
Fig. 2. Schematic form of Cusano light amplifier

consists of an evaporated layer of manganese activated zi sulphide phosphor sandwiched between a transparent co ducting electrode on a glass plate and a metal backing laye The phosphor layer is about 10 μ in thickness and can ha an area of tens of square centimetres. Techniques f making such layers have been described by Cusano ar Studer.(10)

A static voltage giving an average field of up to 10^5 V/c is applied across the layer, but in the dark no appreciab electroluminescence is observed. However, if an ultra-viol or X-ray excited image of low brightness is produced in th layer, then application of the field produces a manifo increase in image brightness. By using ultra-violet light th initial image excitation can be produced at one surface of th layer. Fig. 3 shows the resulting dependence of the luminan of the layer on the d.c. field strength. The sign of the fie for amplification to occur indicates that the carriers involv are electrons. The explanation of the amplifier characteristi in terms of electroluminescence theory has been given Williams.(11) As discussed above, carriers are released light or X-rays and accelerated through the phosphor produce luminescence emission by a collision–recombinati process. The effective gain of the amplifier depends on t applied field strength and also on the initial image intensi in the absence of the field, as shown by the results of Fig. The field has little effect on the luminescence emission chara teristics beyond causing a shift in the peak position of t spectral emission band (100 Å for a field approximate

V/cm). The present efficiency of the device is rather , being about 0·2 lm/W.

he main problem involved in the construction of such an plifier is the production of a uniform thin layer of a able phosphor. So far the only satisfactory material



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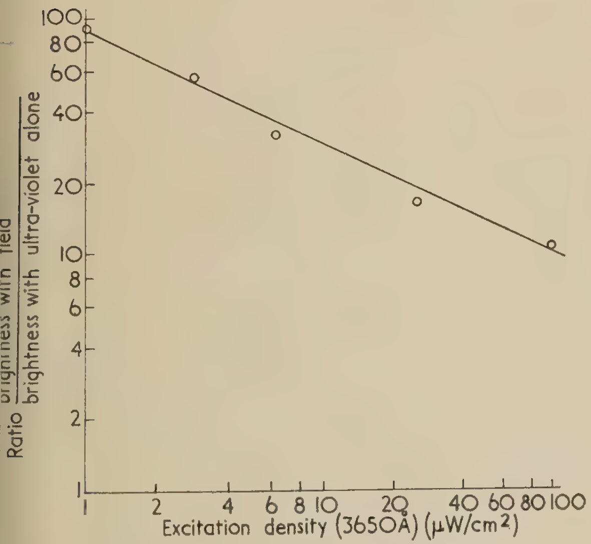
ig. 3. Dependence of phosphor layer luminance and onductivity on applied d.c. field for the Cusano light amplifier



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ig. 4. Dependence of image brightness gain on initial xcitation density of ultra-violet irradiation for a Cusano type light amplifier. Applied field, 10^5 V/cm

been manganese activated zinc sulphide. The layer is ned by the evaporation of zinc and the activating impurity he presence of hydrogen sulphide and also some chlorine. s provides a chemical deposition process. The emission in the orange-yellow region.

3. THE COMPOSITE SOLID STATE AMPLIFIER

(*a*) *General description*

Following the development of improved electroluminescent phosphors Bramley and Rosenthal(12) suggested the use of electroluminescent layers as information display panels since a voltage signal could modulate their emission intensity. In 1953 White(13) suggested the use of a combination of photoconducting and electroluminescent layers as an X-ray image intensifier, and a little later on Orthuber and Ullery(14) put forward the idea of using the same combination as a light amplifier. Since then other papers have appeared on the system as a light amplifier.(6, 15, 16, 17) The schematic form of an amplifier of this type is shown in Fig. 5(*a*) while Fig. 5(*b*) shows the equivalent circuit. The basic idea is to utilize the changes in impedance of the photoconductive layer, due to imposition of the radiation image, to modulate the voltage across the electroluminescent layer. Each layer may be homogeneous in nature (e.g. formed by evaporation) or may consist of a microcrystalline powder dispersed in a suitable dielectric (e.g. Araldite). In the latter case only a.c. fields can be used but layer production is much easier.

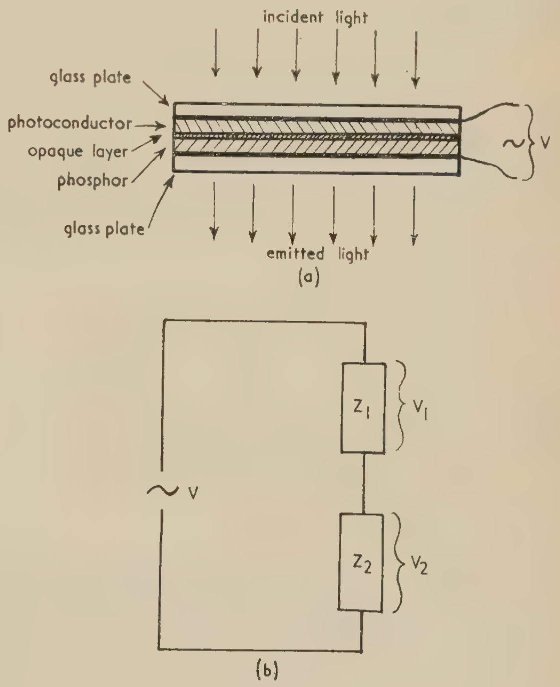

Fig. 5. (*a*) Schematic form of composite photoconductor-phosphor light amplifier
(*b*) Equivalent electrical circuit.

(*b*) *Theoretical assessment of the amplifier performance*

In their paper, Orthuber and Ullery(14) provide a simple expression for the illumination gain of a photoconductor–electroluminescent phosphor device. They assume that the conductivity σ of the photoconductor is given by:

$$\sigma = \gamma I^n \tag{7}$$

where γ and n are constants and I is the primary image intensity. The brightness (B)—voltage (V) relation for the phosphor layer is assumed to be:

$$B = \beta V^m \tag{8}$$

where β and m are constants. The brightness gain is then given as:—

$$G = \frac{B}{I} = \frac{\beta V^m \gamma^m I^{(mn-1)}}{(\gamma^2 I^{2n} + \omega^2 C^2)^{m/2}} \tag{9}$$

where ω is the angular frequency of the applied field and C is the phosphor layer capacity per unit area. Such a simple relation is followed approximately in practice and under limited operational conditions. The most thorough treatment of the amplifier is that due to Diemer, Klasens and van Santen(6) which is summarized below.

(i) *The photoconducting layer.* The photoconductor is assumed to have a dark conductivity σ_0 and an additional conductivity $\Delta\sigma$ due to illumination (light or X-rays, etc.). Using the ideas given in the introduction, the expression for $\Delta\sigma$ is:

$$\Delta\sigma = (e\mu\tau/d_1)I\eta f(\alpha, d_1) \tag{10}$$

where, in addition to previous notation, d_1 is the layer thickness, α the absorption coefficient for the incident radiation and $f(\alpha, d_1)$ the function expressing the absorption process over the thickness involved. In practice the value of $f(\alpha, d_1)$ is about unity and so we omit it in subsequent treatment. The conductance g_1 of the layer is then given by:

$$g_1 = (\sigma_0/d_1) + (e\mu\tau I\eta/d_1^2) = b_1(I_0 + I) \tag{11}$$

where $$b_1 = (e\mu\tau\eta/d_1^2) \text{ and } I_0 = (\sigma_0/b_1 d_1 e\mu\tau\eta) \tag{12}$$

i.e. I_0 is the equivalent radiation density required to produce the conductivity σ_0 in the photoconductor if it is assumed to be insulating in the dark. The quantity b_1 is obviously a measure of the photosensitivity of the layer.

If the admittance of the photoconducting layer is Y_1, its impedance Z_1 and its capacitance C_1 (all refer to unit area of the layer) then we have:

$$Y_1 = 1/Z_1 = g_1 + j\omega C_1 = b_1 I_0 + b_1 I + j\omega C_1 \tag{13}$$

For the efficient operation of the amplifier we thus want I_0 and C_1 to be as small as possible so that the incident radiation produces the largest possible fractional change in Y_1. We shall see later how this is achieved in practical forms of the amplifier.

(ii) *The electroluminescent layer.* The expression for the admittance (Y_2) or the impedance (Z_2) of the electroluminescent layer is simply:

$$Y_2 = 1/Z_2 = g_2 + j\omega C_2 \tag{14}$$

where g_2 is the layer conductance and C_2 its capacitance (again for unit area). In practice g_2 can be assumed to be zero and so it is the reactance which is effective in the behaviour of the layer.

(iii) *The light amplifier performance characteristics.* Referring back to Fig. 5 we see that a voltage $V = V_0 \cos \omega t$ is applied across the photoconductor and phosphor layers which are effectively impedances Z_1 and Z_2 respectively in series. Since the brightness of the phosphor layer is given by the relation of equation (6) we wish to find the change in the voltage V_2 across the layer due to illumination of the photoconductor.

Now $$V_2/V = Z_2/(Z_1 + Z_2) \tag{15}$$

and so $$\left|\frac{V_{20}}{V_0}\right|^2 = \frac{|Z_2|^2}{|Z_1 + Z_2|^2} = \frac{g_a}{g_a + p(p+2)} \tag{16}$$

where $g_a = 1 + (g_1/\omega C_1)^2$; $p = C_2/C_1 = d_1\bar{\epsilon}_2/d_2\bar{\epsilon}_1$

where $\bar{\epsilon}_1$ and $\bar{\epsilon}_2$ are the effective dielectric constants for t photoconducting and electroluminescent layers respectiv and d_2 is the thickness of the latter layer. Using equation we obtain:

$$\frac{B}{\omega B_0} = \exp\left\{-\frac{A}{V_0^{1/2}}\left[1 + \frac{p(p+2)}{g_a}\right]^{1/4}\right\} \qquad (1$$

Now using the value of g_1 from equation (11) and adopting logarithmic form for equation (17) we obtain:

$$\log_e\left[\left(\frac{B}{\omega B_0}\right)^{V_0^{1/2}/A}\right] = -\left[1 + \frac{p(p+2)}{1 + (f_1 I/\omega)^2}\right]^{1/4} \qquad (1$$

where $$f_1 = b_1/C_1 = e\mu\tau\eta/d_1\bar{\epsilon}_1 \qquad (1$$

Equation (18) provides a fairly complete theoretical descri tion of the amplifier performance. It indicates that practice the important factors will be f_1 and p.

To provide an easier indication of performance Dien Klasens and van Santen give a "log.log" graph of $(B/\omega B_0)^{V_0}$ against $(f_1 I)/\omega$ and this is shown in Fig. 6 for different valu

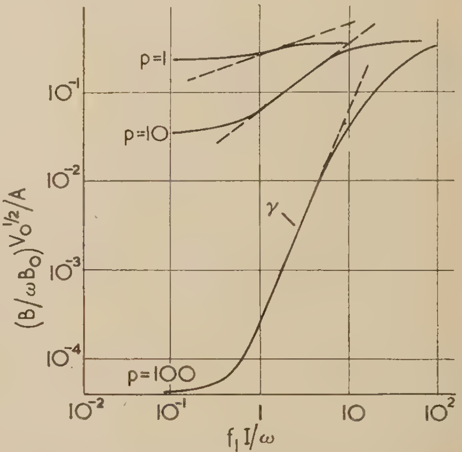

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Fig. 6. Graphical representation of the theoreticall derived characteristics of a composite solid state ligh amplifier

of p (1, 10 and 100). They define a symbol γ as the *contr amplification* and it is represented by the straight line sl of the centre portion of each curve. It can be seen that h contrast requires a large value for p, that is, the relat capacity of the phosphor layer must be high. The choice c also affects the level of brightness in the final image. Incre in field frequency pushes up the brightness level of the out without changing the overall characteristics to any gr extent. The same authors consider the practical case which a cadmium sulphide photoconductor is used in se with a zinc sulphide phosphor as electroluminescent la They give a useful analysis of the effects of different pa meters in relation to the operational requirements. E.g. X-ray image intensification γ should be high and this ne sitates a low effective applied voltage. A high value overall gain requires high p values and also relatively h operating voltages. Certain other features are also mention For instance, if the initial image irradiation is intermitt in character then the relatively slow decay in a cadmi sulphide photoconductor will give rise to storage effects thus to an effective gain in emission brightness.

Diemer, Klasens and van Santen(6) deal with a further int which, as seen later, is of practical importance. This the effect of a "neutral" impedance layer between photo- nductor and phosphor. The effect of such a layer will be uivalent to negative feedback and a fall in contrast and erall amplification will result. In the absence of an inter- ediate layer, and with overlap of the spectral response of e photoconductor with the phosphor emission spectrum, sitive feedback is obviously possible and the system can used as a triggering device.(6, 17)

Practical forms of the solid state amplifier

A simple way of obtaining light amplifier characteristics that adopted by Diemer and others,(6) namely to connect a otoconductive cell and an electroluminescent phosphor ll or panel in series. Fig. 7(*a*) shows the arrangement used Diemer and others, while Fig. 7(*b*) shows typical results

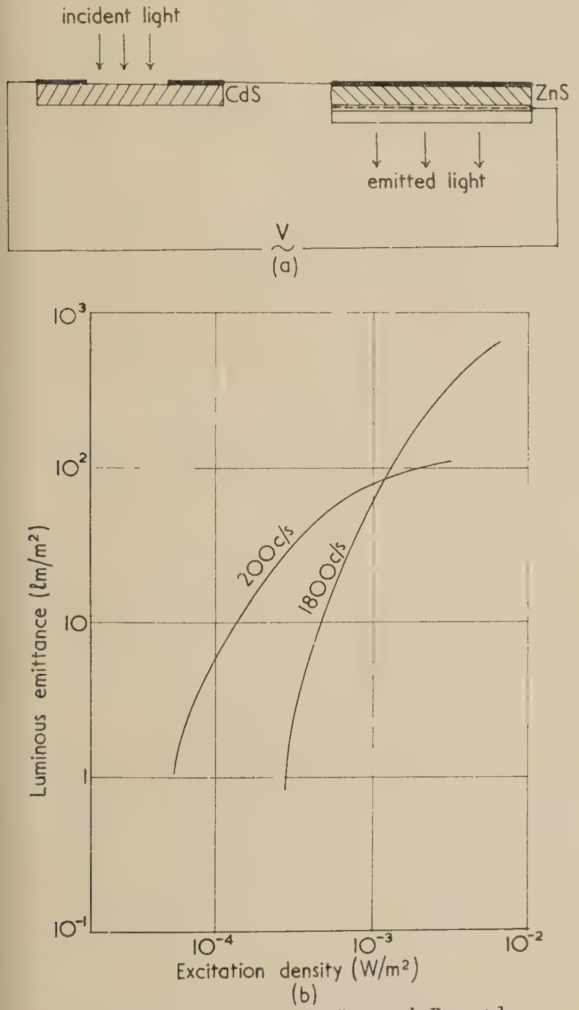

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Fig. 7. Experimental trials of a composite light amplifier:

(*a*) Schematic arrangement of photoconductor and phosphor.
(*b*) Typical results for arrangement of (*a*).

r two different operating frequencies. The phosphor yer can be shorted for measurement of photoconduction aracteristics and *vice versa*. The same workers have vestigated X-ray image intensification with a composite layer amplifier with a photoconductor thickness of half a millimetre (sintered cadmium sulphide activated by copper and gallium) and a phosphor layer (zinc sulphide activated by copper and aluminium) of thickness 50 μ. Optical feedback was minimized by a black opaque layer and increased emission obtained by a white reflecting layer immediately at the rear of the phosphor. These extra layers seriously affected the contrast and overall gain, but an intensification of some thirty times the image brightness of an ordinary radiographic phosphor screen was obtained.

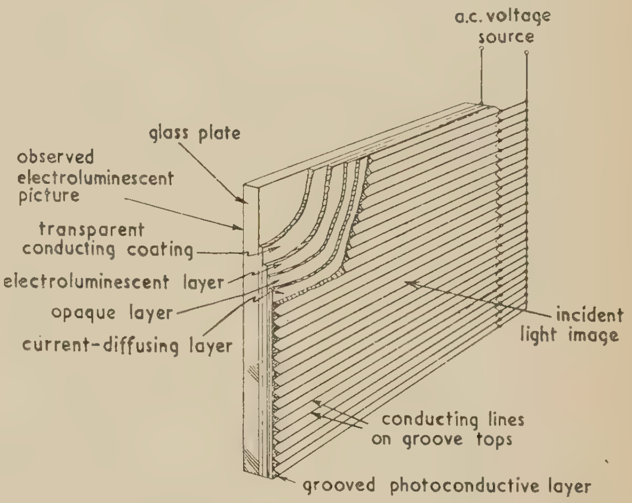
a.c. voltage source
glass plate
observed electroluminescent picture
transparent conducting coating
electroluminescent layer
opaque layer
current-diffusing layer
incident light image
conducting lines on groove tops
grooved photoconductive layer

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Fig. 8. Practical form of image amplifier with grooved photoconductor layer

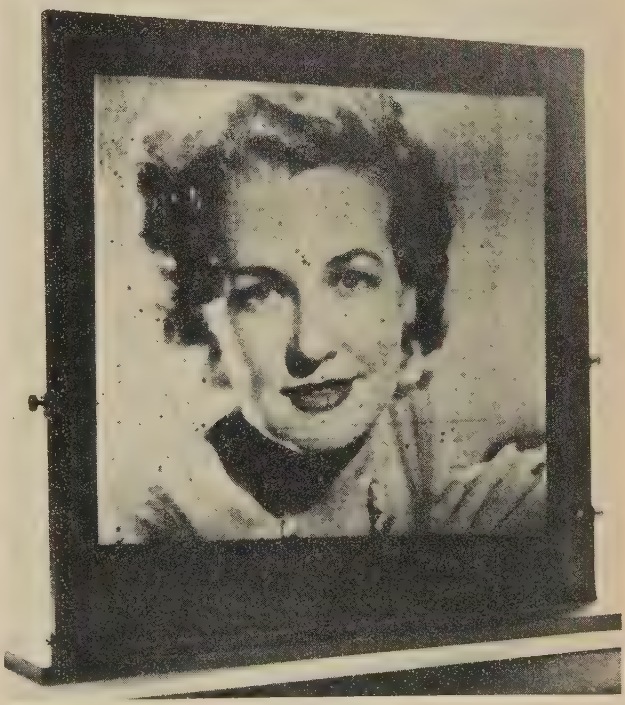

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Fig. 9. Typical image produced by amplifier of Fig. 8

Kazan and Nicoll have reviewed their various attempts to produce such layer type amplifiers.(16) The main difficulty is to obtain a photoconducting layer with a very low dark current but high photosensitivity. To improve the dark impedance they finally adopted the design shown in Fig. 8 with the resultant performance indicated in the photographed image of Fig. 9. The system is built up on a glass plate having a transparent conducting coating on one side. On this coating a thin phosphor layer is sprayed to a thickness of about 0·001 in. An opaque layer of lampblack in Araldite and of smaller thickness is then sprayed on, followed by a 0·02 in. thick layer of semiconducting (but not photoconducting) cadmium sulphide powder in Araldite, known as the current diffusing layer. At this stage the outer surface is machined flat, giving the outer layer a thickness of about 0·01 in. The photoconductor (cadmium sulphide bonded in Araldite diluted with diacetone alcohol) is then applied to a thickness of 0·02 in. and given a surface coating of silver paint. Parallel grooves 0·015 in. deep and 0·025 in. between centres are then machined into the surface, the bottoms of the grooves just penetrating into the current diffusing layer with a line of silver left at the tops of the channels. These silver lines are connected together electrically and form one electrode of the system. The amplifier can be quite large (up to 12 × 12 in.) and resolution is about that of a good television picture. The grooving of the photoconductor provides a much higher effective dark impedance and a lower capacity for the photoconducting layer, thus improving the performance. The current diffusing layer is essential to remove the groove structure from the final image but, as expected from discussion above, this layer interposed in the system has a bad effect on contrast and overall gain. The response speed and decay time of the photoconductor are strongly influenced by the type of bonding used for the microcrystalline materials which introduces a further problem into the design of efficient amplifiers. Fig. 10 shows typical output *versus* input data for this amplifier while Fig. 11 shows the relation between gain and input light level.

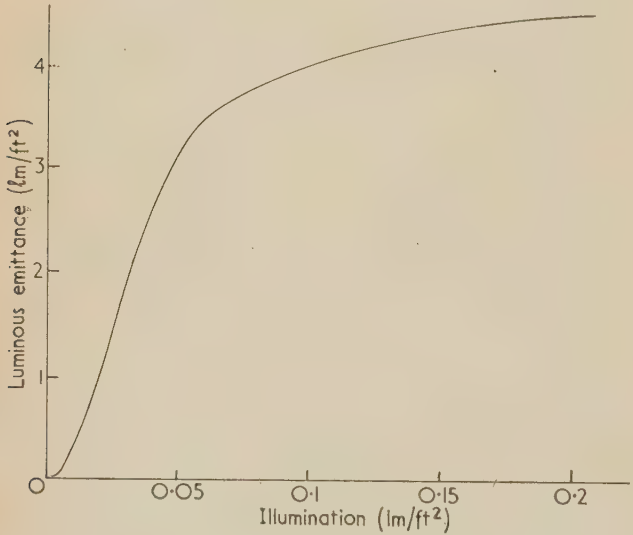

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Fig. 10. Luminous emittance: input image illumination relation for the amplifier of Fig. 8

Some amplification for direct X-ray images is claimed, but the system can also be used indirectly in contact with standard X-ray fluoroscope screen. Some advantage migh be obtained by reduction of the thickness of the opaqu layer to give a limited amount of positive feedback. Thi would increase both contrast and overall gain.

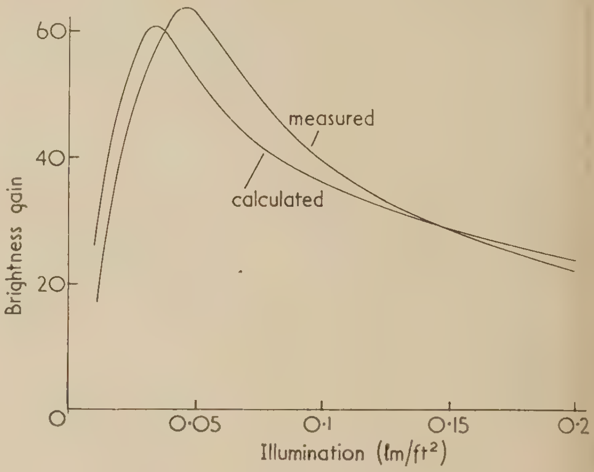

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Fig. 11. Relation between brightness gain and input image illumination for amplifier of Fig. 8

4. FUTURE POSSIBILITIES

It will be seen that the large area solid state light ampli is built up either from sintered layers of photoconductor an phosphor, etc., or from layers of microcrystalline materia bonded in a suitable resin. However, the simple device c Cusano uses a single, evaporated phosphor layer. For bot types of amplifier much would be gained by fundament research on the problems of producing efficient thin fil specimens of phosphors and photoconductors. In the ca of phosphors a useful gain would be made by making coppe activated zinc sulphide in this form. Cusano's technique might be used to form the zinc sulphide film, activation b copper and other impurities being effected by subseque treatments. Recently Feldman and O'Hara(18) have give an account of methods of producing reasonably efficie phosphor films by vacuum evaporation and subsequent hea treatment. The phosphors studied included zinc sulphide silicate and phosphate and also calcium fluoride and tungstate With respect to the photoconductor, present attention appear to be too much confined to varieties of cadmium sulphide Less usual photoconductors might be investigated in thi film form, e.g. lead oxide. Whilst current multiplication an storage effects (large τ) in cadmium sulphide offer som advantages these are offset by the relatively low dar impedance.

Operated at low temperatures the solid state image amplifie may provide a useful image converter for the infra-red regio up to a limit of several microns (of the order of 6 μ). Mad with an ultra-violet sensitive photoconductor (or even in th simple Cusano form) it would have attractions over the con ventional vacuum image tube for the ultra-violet microscopist since it has an effectively two-dimensional form and does no require very high voltages. There are possibilities for use o the device as a nuclear particle detector though initial result do not appear to be too promising.

ACKNOWLEDGEMENTS

Thanks are due to the following authors for permission to eproduce diagrams from their publications: Dr. D. A. Cusano (Figs. 3 and 4); Dr. Diemer and colleagues [Figs. 6, (*a*) and (7*b*)]; and Drs. Kazan and Nicoll (Figs. 8, 9, 10 and 11).

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ORIGINAL CONTRIBUTIONS

The Hall-effect compass

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Recent work on semi-conductors has led to materials in which the Hall effect in the earth's magnetic field is strong enough to form the basis of a simple electrical compass. The theory of the device is briefly presented and expressions derived for the voltage and power output, and the ultimate sensitivity obtainable. The comparative merits of various semi-conductors are shown in tabular form; this information should be useful also for other devices based on the Hall effect.

An experimental compass unit is described, which had a power output of 6×10^{-9} W/degree of arc. Various possible systems using such a unit are briefly discussed, including the use of super-regeneration for increasing the power available.

INTRODUCTION

Over 70 years ago Righi(1) showed that it was possible to observe the orientation of the earth's magnetic field by using he Hall effect in a plate of bismuth. However, the development of this idea to a practical stage seems to have been neglected until recently, when the discovery of materials of much greater Hall efficiency has drawn new attention to the possibility.(2)

In this paper the main features of the compass element are discussed, together with some practical details of construction and preliminary experimental results. Little work has yet been done on complete systems, but a brief account is given of various ways in which this compass principle might be used n practice.

THEORY

The principle of the compass is illustrated in Fig. 1. A ectangular block of crystal† of a suitable material, of dimensions x, y, z cm is fitted with end electrodes, by means of which a steady current I_x (A) is passed in the direction shown. To the top and bottom faces are fixed centrally two additional short electrodes, across which a Hall voltage V_z is developed

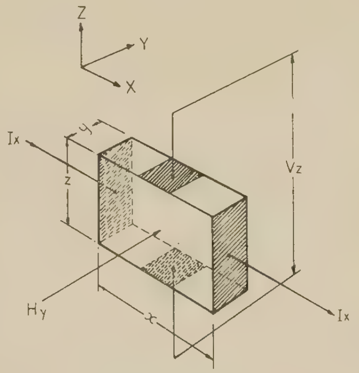

Fig. 1. Principle of the Hall compass

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† The block will normally be single-crystal, but not necessarily so.

in the presence of a magnetic field H. This voltage is given by the well-known expression

$$V_z = \frac{10^{-8}RI_x}{y} \cdot H_y \tag{1}$$

where R is the Hall constant of the material (in cm^3/coulomb) and H_y is the transverse component of the applied field. H is measured in oersteds. Thus if the Hall axis z is kept vertical and the crystal rotated to different orientations in the earth's field the output voltage is given by

$$V_z = \frac{10^{-8}RI_x}{y} H_h \cos\theta \tag{2}$$

where H_h is the horizontal component of the earth's field and θ is the angle between the magnetic meridian and the y direction. The output will thus vary with azimuth as shown in Fig. 2.

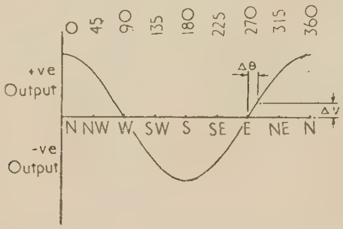

Fig. 2. Angular response of compass element

It will be noted that for a given output the value of θ is ambiguous, i.e. is only determined to within a reflection in the meridian. Also, there are two null points, corresponding to E and W orientation. In these positions the angular discrimination is relatively high, but falls off to zero in the N and S directions.

Because of the variation in discrimination most practical uses of such a compass element are likely to involve null-working. The output of interest will be that obtained for a small departure, $\Delta\theta$, from null. From (2) this will be given in magnitude by:

$$V_z = \frac{10^{-8}RI_x}{y} \cdot H_h\Delta\theta \tag{3}$$

The problem of ambiguity in θ is not a serious one, as will be shown later.

If the Hall electrodes are connected to a matched load the power W_0 delivered to the latter is given by

$$W_0 = \frac{V_z^2}{4r} \tag{4}$$

where r is the internal resistance of the crystal, between the Hall electrodes.

From the geometry of the crystal,

$$r = s \cdot \frac{\rho z}{xy} \tag{5}$$

where ρ is the resistivity and s is a factor, of the order of unity, which allows for the spreading resistance at the Hall electrodes.

The power W_i dissipated in the crystal by the input current is given by:—

$$W_i = I_z^2 \frac{x}{yz} \rho \tag{6}$$

Combining (2), (4), (5) and (6) we obtain

$$W_0 = W_i \frac{10^{-16}}{4s} \cdot \left(\frac{R}{\rho}\right)^2 H_h^2 \cos^2\theta \tag{7}$$

In the same way V_z may be expressed in terms of similar factors to give

$$V_z = 10^{-8}\sqrt{(W_i)}\sqrt{\left(\frac{z}{xy}\right)}\ \frac{R}{\sqrt{\rho}} H_h \cos\theta \tag{8}$$

Equations (7) and (8) are only strictly true for small values of H, when magnetoresistance effects, which are quadratic in H, can be neglected. They are very good approximations for the fields concerned here.

So far only the d.c. case has been considered, but I_x may also be a.c. Provided that the frequency is not so high as to cause appreciable skin effects formulae analogous to (7) and (8) apply with obvious modifications. The Hall output is now also a.c. with the same frequency.

CHOICE OF CRYSTAL MATERIAL

This will depend principally on the type of output needed, i.e. whether voltage, or power output is required, but the temperature coefficient permissible may also influence the choice. Economy in the input supply and convenience of matching are other important practical considerations, particularly when d.c. drive is used.

In output requirement three cases can be distinguished:

Case A. The device has to feed a valve, or other high-impedance amplifier and is working at a level well above its own internal noise. The need here is for a high open circuit voltage. Equation (8) shows that, if geometrical factors are ignored, this will be obtained for a high value of $R/\sqrt{\rho}$. It is convenient for later discussion to express this in the form $(\mu R)^{\frac{1}{2}}$, where μ is the electron mobility. This equivalence is strictly true for conduction by one type of carrier only, but is sufficiently accurate for the cases considered, in which electronic conduction preponderates over hole conduction. Values of this factor are given in table 1 for a number of materials of interest.

Case B. The device has to operate directly a relay, or indicating instrument. The need will be for maximum output power into a matched load. From equation (7) it will be seen that the requirement is for a large value of $(R/\rho)^2$, which is equivalent to having a large value of μ^2. Values of this factor are also included in table 1.

Case C. The third case of interest is that in which the device has to be able to detect the smallest possible value of $\Delta\theta$. This value can be taken as that for which the change in output power just equals the average noise power in the crystal. This will depend on the effective noise-bandwidth Δf, which in turn will be determined by the response time desired; a nominal value of 1 c/s will be assumed here, corresponding to a response time of 1 s. If the only noise present were that due to thermal noise in the crystal the average noise power would be that given by the Nyquist expression $\overline{W_n} = kT\Delta f$ which is equal to $4{\cdot}7 \times 10^{-21}$ W for $\Delta f = 1$ c/s and $T = 300°$ K. The minimum detectable value of $\Delta\theta$ (from the null position) is then obtained by equating this to the expression in equation (7) with $\cos^2\theta$ replaced by $(\Delta\theta)^2$. For $\Delta\theta$ to be small ρ/R must be small, i.e. $1/\mu$ must be small. Values of this fraction also are included in table 1.

In practice, the noise in a semiconductor is usually in excess of thermodynamic noise, by an amount which depends on extraneous properties, such as surface condition. It is therefore not possible to put the various materials into order on a purely theoretical basis. However, it is found experimentally that in the case of InSb excess noise is absent.$^{(3)}$ This, together with the very low value of $1/\mu$ for this material,

Table 1. *Comparative sensitivity of various materials, assuming negligible temperature rise*

Material	*Bi*	*Ge (N type)*			*Si (N type)*		*InSb (intrinsic)*	*InAs (N type)*		
Ω cm)	$1\cdot8 \times 10^{-3}$	1	5	25	1	4	5×10^{-3}	5×10^{-3}	$2\cdot0 \times 10^{-2}$	$1\cdot0 \times 10^{-1}$
o. of carriers	$\sim 6 \times 10^{17}$	$1\cdot7 \times 10^{15}$	$3\cdot5 \times 10^{14}$	5×10^{13}	$5\cdot1 \times 10^{15}$	1×10^{15}	2×10^{16}	$5\cdot45 \times 10^{16}$	$1\cdot1 \times 10^{16}$	$1\cdot67 \times 10^{15}$
all constant R(cm³/coulomb)	5–10	4250	21 000	87 000	1420	7100	380	115	570	3700
obility μ(cm³/V s)	5000	3500	3600	3600	1200	1200	65 000	23 000	28 000	35 000
$\frac{1}{R}\frac{dR}{dT}$(%/° C)	$\sim 0\cdot4$	$\sim 5 \times 10^{-3}$	$0\cdot3$	4	*Negligible*		2	6×10^{-3}	$0\cdot15$	~3
of merit: Voltage output $\propto(\mu R)^{1/2}$	1 $(0\cdot84-1\cdot15)$	20	45	90	$6\cdot8$	15	26	$8\cdot4$	21	60
Power output $\propto(\mu)^2$	1	$0\cdot5$	$0\cdot5$	$0\cdot5$	$0\cdot06$	$0\cdot06$	170	21	32	48
Minimum detectable angle $\propto 1/\mu$	1	$1\cdot4$	$1\cdot4$	$1\cdot4$	$4\cdot2$	$4\cdot2$	$0\cdot08$	$0\cdot22$	$0\cdot18$	$0\cdot14$

* Normalized to unity for bismuth.

ieans that for obtaining ultimate sensitivity it is the best of xisting materials.

Temperature dependence of the output will be more erious in some applications than in others. It will be serious vhere the compass is required to turn with the craft and give ie correct reading at any bearing. On the other hand, if nullvorking is used, a change in temperature will merely give a mall change in sensitivity, without affecting the zero accuracy.

The variation with temperature has two contributory causes riginating in the crystal material. The first is the change in urrent-carrier density with temperature, which gives rise o an inversely proportional change in the Hall constant R. 'he second is the change in carrier mobility μ, due to the ariation in the degree of scattering.

The change in R will be least when the material is strongly or p type and working under exhaustion conditions, i.e. vith all the dominant impurity centres ionized. Conversely he greatest dependence will occur when the material is intrinsic." This is illustrated in table 1 where values of

$$\frac{1}{R}\cdot\frac{dR}{dT}$$

re given for the various materials. For germanium the Ω cm material is in the exhaustion range at room temerature, whereas 25 Ω cm material is approaching the ntrinsic case. The coefficients themselves are, of course, emperature dependent, and values given apply only to small xcursions (e.g. 10° C) from room temperature.

The change in μ with temperature is too complex to discuss riefly, but for the materials listed in table 1 it can be assumed hat "lattice" scattering is dominant and that μ therefore aries approximately as $T^{-3/2}$. This gives for $\frac{1}{\mu}\frac{d\mu}{dT}$ the alue of 0·5%/°C, at room temperature.

The way in which R and μ combine to give the total coeffiient depends on input conditions and on the type of output equired. For example, for constant input current and onstant load the voltage coefficient is given by:

$$\left.\begin{aligned} &\frac{1}{V_z}\frac{dV_z}{dT} = \frac{1}{R}\frac{dR}{dT} \\ &\text{nd that for power, for the one carrier case, by} \\ &\frac{1}{W_0}\frac{dW_0}{dT} = \frac{1}{R}\frac{dR}{dT} + \frac{1d\mu}{\mu dT} \end{aligned}\right\} \quad (9)$$

whereas for constant input voltage the corresponding equations are:

$$\frac{1}{V_z}\frac{dV_z}{dT} = \frac{1}{\mu}\frac{d\mu}{dT} \text{ and}$$

$$\frac{1}{W_0}\frac{dW_0}{dT} = \frac{3d\mu}{\mu dT} - \frac{1}{R}\frac{dR}{dT} \quad (10)$$

Values of these coefficients may be derived from the table, but in practice the input arrangement may lie intermediate between those given, and of course load variation with temperature will also have to be taken into account. Mismatch also may occur and may be used intentionally to compensate the coefficient.

Summarizing the results of the table it can be said that where temperature dependence is not important the highest voltage output is obtained with fairly pure germanium (~ 25 Ω cm) and the best power output and sensitivity with InSb. Where good temperature behaviour is also necessary germanium is still the best material for voltage output. It should be fed with constant current and be of rather lower resistivity, e.g. 5 Ω cm for a coefficient of −0·3% and 1 Ω cm for 5×10^{-3}%/°C. For power output constant voltage feed is preferable. InSb has then a coefficient of −0·5%/°C into a constant load. If the load is increased to twice the matched value the coefficient becomes approximately zero, over a limited temperature range, for a loss of only some 6% in output power.

The factors of merit given in table 1 are calculated for the case of negligible temperature rise in the crystal. Greater output can, of course, be obtained by increasing the input power still further. The change in μ will be approximately the same in all cases, hence the relative performance in the last two rows will not be altered. The presence of the $R^{\frac{1}{2}}$ factor in the voltage case, however, will lead to a relative change. For example, in table 2 the last three rows of table 1 have been recalculated for the case of a 50° C temperature rise in the material. Corrections have been applied for two-carrier conduction where necessary.

It will be seen that under this condition silicon is approaching germanium in voltage sensitivity and that high resistivity InAs is better than either. The use of such high temperature rises, however, may involve difficulties due to thermoelectric effects. The neglect of excess noise must also be remembered in considering minimum detectable angle.

Table 2. *Comparative sensitivities of various materials for a 50° C temperature rise above ambient* (20° C)

(To be compared with the last three rows of table 1)

	Ge			*Si*		*InSb*	*InAs*		
Factor of merit	1	5	25	1	5	5×10^{-3}	5×10^{-3}	2×10^{-2}	10^{-1}
oltage output	$18\cdot3$	32	31	$7\cdot2$	16	$15\cdot9$	$8\cdot5$	$19\cdot5$	37
ower output	$0\cdot33$	$0\cdot27$	$0\cdot15$	$0\cdot05$	$0\cdot05$	104	16	21	31
inimum detectable angle	$1\cdot75$	$1\cdot92$	$2\cdot6$	$4\cdot5$	$4\cdot5$	$0\cdot1$	$0\cdot25$	$0\cdot22$	$0\cdot18$

SENSITIVITY OBTAINABLE

This can be obtained directly by substituting typical values in the equations developed above. To show the order of magnitude involved, results are quoted below for the case of a crystal measuring 1 × 0·5 × 0·025 cm, in which the permissible input dissipation is taken as ¼ W. This will give rise to negligible increase in temperature if the precaution is taken of mounting the crystal in good thermal contact with a larger copper block.

Case A—voltage output. Using germanium of 25 Ω cm *n* type, we obtain

$$V_z = 10^{-7}\text{ V/deg. of arc at the null position.}$$

Case B—power output. The use of InSb is assumed. From expression (5)

$$W_0 = 2{\cdot}3 \times 10^{-13}\text{ W/deg. of arc.}$$

This is well below the level of available relays. For example, the Carpenter type 3 telegraph relay requires $\sim 5\times10^{-6}$ W for operation. The most sensitive moving coil relay is quoted as 10^{-10} W, although operation is not very reliable at this level. It is seen, therefore, that a much larger crystal would be required before it would be possible to operate even the most sensitive relay directly. Alternatively some concentration of the earth's field is needed, as discussed later.

Case C—ultimate sensitivity. Again InSb is assumed. Using formulae (7) the change in θ required at null to give a matched output power equal to the noise power in 1 c/s bandwidth is

$$\Delta\theta \simeq 1\text{ minute of arc.}$$

In practice other factors may set the limit, such as the occurrence of thermomagnetic and thermoelectric effects. If a.c. drive is used, however, most of those stray effects can be filtered out and a close approach to the theoretical limit should be possible.

In Fig. 3 is shown the output obtained when a field of 10^{-2} oersted produced by a known current in a single-turn coil is applied to a specimen of dimensions 6 × 3 × 0·25 mm carrying 30 mA current. The Hall contacts were connected to a d.c. amplifier of 2 c/s bandwidth. Under these conditions the theoretical value of minimum detectable angle would be given by $\Delta\theta = 2'$. From the figure it is estimated that for signal equal to noise a step of 4×10^{-4} oersted would be required, corresponding to a value of $\Delta\theta = 8'$. Some of the measured noise may be due to external interference, and better agreement could be expected with a screened crystal.

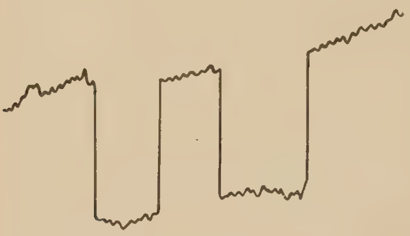

Fig. 3. Typical response after amplification (the step corresponds to a field change of 10^{-2} oersted

USE OF CONCENTRATORS

The power output for a given angular deflexion can b greatly increased by collecting the earth's field and concentrating in on the specimen by rods of high permeability material, such as Mumetal or Permalloy C. The arrangemen is shown schematically in Fig. 4 in which the central gap ha been enlarged to show the Hall specimen more clearly.

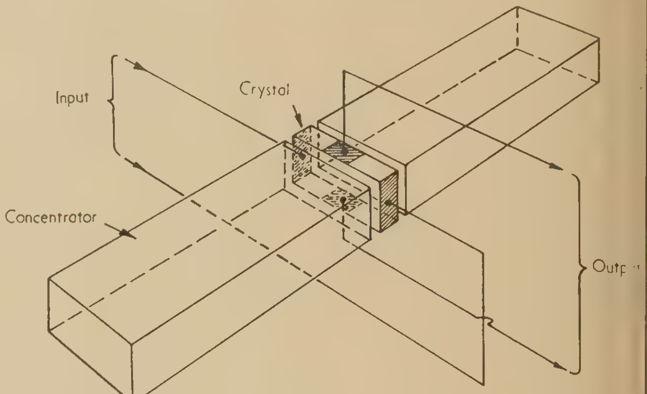

Fig. 4. Compass unit using concentrators

The effective permeability of the material is reduced fro the toroidal value by the demagnetizing effect in the ro and also by the gap required. In Fig. 5 is shown the effectiv permeability obtainable as a function of gap-width for tw representative values of length/diameter ratio. It will

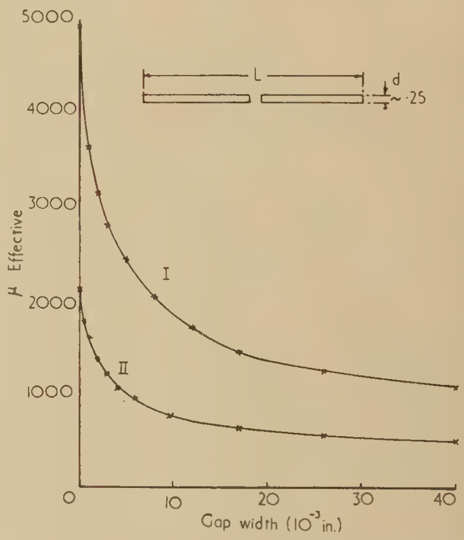

Fig. 5. Effective permeability of Permalloy C rods with central air gaps (measured in earth's field)

Rod I, total length to diameter ratio = 180; rod II, total length to diameter ratio = 112; effective permeability = (total flux across gap)/(field × area).

seen that a very large factor of improvement is obtainab without undue size of the rods. For example, with the cryst size used in the cases calculated above, a total length o 30 in. would give a thousandfold increase in field. In cas *B* the power available for one degree deflexion is raise to $2{\cdot}3 \times 10^{-7}$ W, which is sufficient to operate the mos sensitive type of relay.

The use of concentrators, however, introduces hysteresis fficulties. If the rods, from an initial null position are run saturation in one direction the zero position will change an angle given by $H_h \sin \theta = H_c$, the coercive force of the aterial. This is of the order of 0·03 oersted for Mumetal. owever, in a practical case the rods would not approach turation: for $\mu_{eff} = 1000$, for example, the value of B_{max} ll be 180 G as compared with the saturation value of 00 G. The corresponding hysteresis error will be 0·5°, hich is probably tolerable for ordinary navigational purses. If the compass is used only in the null orientation, to dicate temporary deviations from course, the cyclic hysteresis ror will be negligibly small.

In cases where the hysteresis error is important a comomise would be the use of shorter concentrators. Altertively the use of Supermalloy as the magnetic material ould reduce the error by a factor of approximately 10.

CONSTRUCTION OF AN EXPERIMENTAL UNIT

The construction of an experimental compass unit of the ncentrator type is shown in Fig. 6, which should be mpared with a photograph of an actual unit in Fig. 7.

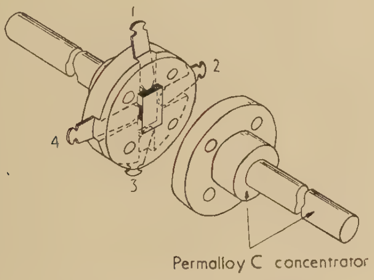

Fig. 6. Crystal mount

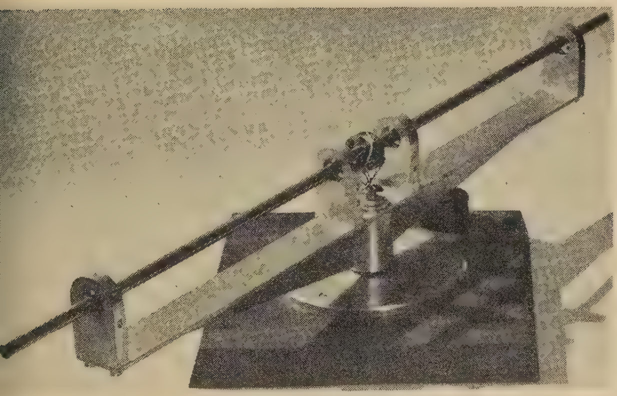

Fig. 7. Actual compass unit

slice of single crystal InSb is cut and ground to the size 0 × 0·5 × 0·1 cm, and mounted by means of thin film bitumen on to a Permalloy C pole-piece of the same crossction. The pole-piece itself is embedded in a plastic surund, which serves to locate the four electrodes, which nsist of copper foil 0·005 in. thick. Contact between the ectrodes and the crystal is made by electro-plating, those rts of the crystal not required to be plated being protected cellulose paint. After plating, the crystal and electrode are embedded in a thin layer of cold setting resin, and the crystal then ground down to its final thickness, which is usually in the region of 0·005 to 0·010 in. The other pole-piece, also in a plastic surround to facilitate fixing, is clamped to the first, a thin layer of bitumen again being interposed as insulation. The main Permalloy C rods are then screwed into the pole-pieces to complete the magnetic assembly.

To cancel out the zero-field Hall signal, which arises either from inhomogeneity of the crystal or errors in the geometry of the crystal or electrodes, the compensating network devised by Kuhrt(4) was used. As this method involves the insertion of some series resistance in the output circuit it leads to a loss of output power, depending on the amount of correction required. To keep this to a minimum precision methods were used for grinding the crystal to size and for positioning the Hall electrodes prior to plating. In typical cases the residual loss of output power was of the order of 10%.

In a particular unit of this type the crystal was reduced to 0·008 in. thickness giving a longitudinal resistance of 1 Ω and a Hall resistance of 0·6 Ω. The Permalloy rods had a total length of 24 in. and an estimated gap of 0·010 in. With a feed current of 1 A the sensitivity was such that 1° deflexion from E–W orientation gave an open circuit output of 0·12 mV. This corresponds to power output of 6×10^{-9} W/degree of arc. The theoretical figure, assuming the best published data for the magnetic material and the maximum mobility of the InSb is 8×10^{-8} W/degree of arc. The difference is probably accounted for partly by the use of rather lower grade InSb ($\mu = 55\,000$ as against 65 000), partly by residual strain in the rods, which would reduce the permeability by a considerable factor, and partly by error in estimate of the gap. However, these results show the large increase in available power which can be obtained by the use of concentrators and indicate that the operation of a relay direct from the compass is not an impracticable target.

With the output of this unit fed to a Negretti and Zambra 6 Ω moving-coil galvanometer a very effective dead-beat action was obtained, the response time being of the order 1/5 s. At a current of 1 A the warm-up time of the unit was less than 10 min after which the calibration became stable.

A check of hysteresis on this unit showed that there was a difference of 3° in the orientation for zero output after traversing respectively a N–S and a S–N orientation. The azimuthal equivalent of the coercive force is thus 1·5° which is several times higher than that expected for the Permalloy used and consistent again with residual strain. Some experimental observations were also made of temperature dependence. The voltage change obtained for a fixed value of $\Delta\theta$ was measured over a range of temperatures. The results corresponded at room temperature to a coefficient of $-0{\cdot}75\%/°\mathrm{C}$.

USE OF REGENERATION

It is possible to tap off some of the output power and use it to increase the effective field at the crystal, thus giving positive regeneration. If concentrators are not used, the increase in sensitivity obtainable in this way is small. With concentrators, on the other hand, the total loop gain can be made greater than unity so that the system becomes unstable, with the core running to saturation in either direction, depending on the initial magnetization. For example, this state was obtained with the unit described above when the Hall output was fed to two paralleled 600 turn coils wound on the concentrators and matched to the Hall resistance.

The use of regeneration for obtaining a straightforward increase in sensitivity is not particularly useful since the hysteresis error will also increase. It would be preferable to obtain the same gain by a separate amplifier. However, it opens up the possibility of using super-regenerative working, which would provide large output powers with very little complexity. This is referred to in more detail below.

SYSTEMS

There are several possible ways in which the Hall-effect compass principle might be used in practice. A brief description only is given here, and no reference is made to problems common to all compasses, such as the need to avoid tilt.

Direct-reading compass. The simple system in which the Hall output is fed direct to an indicating meter would not be attractive in practice. The ambiguity in θ, together with the fall off in angular discrimination towards the meridian are serious disadvantages. Some system of compensation would also have to be used to reduce the temperature coefficient.

Null-working compass. In this the disadvantages of the simple system are overcome by using it as a null indicating device. The compass unit, carrying the compass card is rotated manually until zero output is obtained, when the card should be correctly aligned. It is still necessary to distinguish between E–W and W–E, but this is easily done by using a definite routine in the approach to zero, e.g. by always starting with the output error in the same direction and making the main correction by a rotation in a given sense. Once the course is correctly set this type of unit would provide a simple yet sensitive indicator for manual steering.

Automatic compass. The error signal arising from the null-indicating compass can be used to operate a servo system, thus keeping the compass card in its correct alignment. In its simplest form the signal would operate directly a centre-stable relay, through which the correction motor is controlled. The servo system could also operate a number of repeaters if necessary. The master unit in this case could be mounted in the best position magnetically without regard to the need for direct viewing.

Automatic steering. In this case the servo correction is applied to the ship's rudder. The simple relay-operated system would provide an inexpensive form of automatic steering for small craft.

X–Y compass. Most of the disadvantages of the direct-reading compass can be overcome if two horizontal units are used, mounted at right angles to one another. One unit thus measures $H_h \cos \theta$ and the other $H_h \sin \theta$. These signals can be combined in various ways to indicate the bearing of the vessel, e.g. by feeding them, after amplification, to the x, y plates, or sweep coils, of an oscilloscope. Angular discrimination is now constant, independent of θ. Also temperature and feed current changes cancel out, to a first order. Remote indication is possible and a number of repeaters can easily be operated from the same unit.

X–Y–Z system. By using 3 units mounted orthogonally to one another complete information is provided of the attitude of the craft relative to the earth's magnetic vector in space. This could be used to replace one gyro in a space reference system, at least over limited regions where the orientation of the earth's vector is accurately known. By squaring and adding the three components in an analogue network the total strength of the earth's field is obtained.

Gradiometer. This is not in itself a compass but consists of two parallel units spaced apart but rigidly connected to one another. The Hall outputs are connected in series opposition and balanced off against one another. Thus in a uniform field no resultant signal is obtained for any orientation, but the system will be sensitive to field gradients.

Super-regenerative system. In this the Hall output is fed to windings on the concentrators so arranged that the loop gain is greater than unity. The output thus rises until saturation of the core material sets in. By means of a rotating switch and relay the regeneration circuit is then interrupted and a pulse of current in the correct sense applied to the core to cancel the remanence. Regeneration is then reapplied and the current builds up as before, this cycle being repeated indefinitely. The direction of build-up during each cycle will be determined partly by any remanence remaining after cancellation and partly by the error signal due to deviation from course. If the former is made small by careful design the system will be sensitive to correspondingly small error angles. However, the output power available in each case corresponds to core saturation and is independent of the sensitivity.

ACKNOWLEDGEMENT

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Experiments using a simple thermal comparator for measurement of thermal conductivity, surface roughness and thickness of foils or of surface deposits

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The thermal comparator described consists of two metal balls similarly mounted in a block of balsa wood, but one is at a slightly lower level so that it touches any surface on which the block rests. After heating to a small fixed temperature excess the block is laid in contact with the test surface. Differentially connected thermocouples attached to each ball measure the increased rate of cooling of the ball which makes contact. The differential e.m.f. is observed 10 s after contact is made and is shown to be a function of the thermal conductivity of the material on which the ball rests. When calibrated in terms of at least two substances of known thermal conductivity, determinations of thermal conductivity can be quickly made. The accuracy from single readings made on several alloys of iron, aluminium and magnesium is about ±6%, but lead departs considerably, due, it is thought, to its softness.

The condition of the surface affects the readings, so the calibration should be made for a similar surface condition. Alternatively, the device can be used as a means of measuring surface finish. Other possible uses are for measuring the thickness of surface deposits and for non-destructive sorting or identification of solid materials.

TRODUCTION AND OUTLINE OF PROPOSED TEST METHOD

eat transfer plays an important role in the performance of omic reactors, rockets and jet engines, to mention only ree of the projects on which considerable research and velopment work is in progress. The post-war era has nsequently seen a substantial increase in the interest shown the thermal properties of materials, particularly in deter- inations of thermal conductivity. Whereas electrical con- ictivity determinations are relatively simple to undertake ere are two vital differences between the conduction of at and electricity which contribute to the enormously eater difficulties associated with an accurate thermal con- ictivity determination. These are the considerable time ually required for the establishment of a steady flow of at and the lack of any perfect thermal insulator. In conse- ence, the measurement of electrical conductivity has variable appeared to be an easier and more rapid measure- ent than that of thermal conductivity. Indeed, for electrical nductors, approximate thermal conductivity values are not frequently deduced from electrical conductivity measure- ents.(1) Furthermore, there are several types of electrical nductivity meter available giving direct readings of the ectrical conductivity, or of the reciprocal quantity, the ectrical resistivity. These have naturally found applications r non-destructive testing.

The writer recently had occasion to consider thermal con- ictivity as the basis of non-destructive test methods,(2) and o favourable factors were readily appreciated. One was a rect consequence of the aforementioned disadvantage, mely the lack of a perfect heat insulator. Since all materials conduct heat it follows that any non-destructive test based the thermal conducting properties of a substance would of more general applicability than one based on electrical nducting properties.

The second was the realization that for many years past ermal conductivity had been used as the basis of a handling t, which is surely the simplest of all non-destructive tests. merely handling solid objects that have attained normal om-temperature equilibrium it is possible to grade them cording to their thermal-conductivity values. A substance high thermal conductivity feels cold on first touching whilst a substance of lower thermal conductivity feels relatively warm. The rate of heat transference from the hand to the solid is primarily a function of the thermal conductivity of the latter. What simpler or speedier test could be desired than one in which the sample is merely touched by hand?

The thermal comparator,(3) which forms the subject of the present paper, is a device which is more sensitive than most hands and which seeks to translate the sensations of "warmth" and "cold" to readily measurable quantities. The increase in the rate of cooling, or heating, through a specified temperature range of the comparator when brought into contact with the test material over the rate when freely cooling, or heating, serves as a measure of the quantity required. By keeping the contacting area small it would seem that the variable state becomes of very short duration so that the experiment is conducted under relatively steady thermal conditions, when the thermal resistance governing the rate of heat transfer is primarily a function of the thermal conductivity of the material under test.

The method is essentially a comparative one and calibration using materials of known thermal conductivity is necessary. It will be appreciated that the proposed method is distinctive in that the associated measurements are all made quite independently of the material under test. The method is therefore one which clearly fulfils the requirements of a non-destructive test.

The account which follows should be regarded as somewhat in the nature of a progress report. Whilst it is felt that sufficient results have been obtained to justify publication at this stage, it is realized that further investigations are still required before the possibilities and limitations of the proposed method can be fully established. This work is being actively pursued.

DESCRIPTION OF THERMAL COMPARATOR AND EARLY TESTS

The measuring device developed consists of two similar phosphor-bronze or other metal balls of diameters ranging from 1/8–5/16 in. securely mounted in a block of balsa wood or other thermal insulation. The device, which is being called a thermal comparator, is sketched in Fig. 1. The balls are so positioned that the base of one is just within the base of the block, but that of the other projects slightly. This arrangement ensures that any heat interchange with the surroundings will be much the same for both balls and permits one of the balls to be placed in contact with the surface of the material under test. Connected to each ball is a thermocouple and it is arranged that the thermal e.m.f.'s of the two thermocouples can be read separately or differentially. For the experiments to be first described the thermocouples were of No. 26 s.w.g. chromel and constantan wires, giving an e.m.f. of the order of 75 μV per °C and the observations were made on a vernier potentiometer reading to 1 μV.

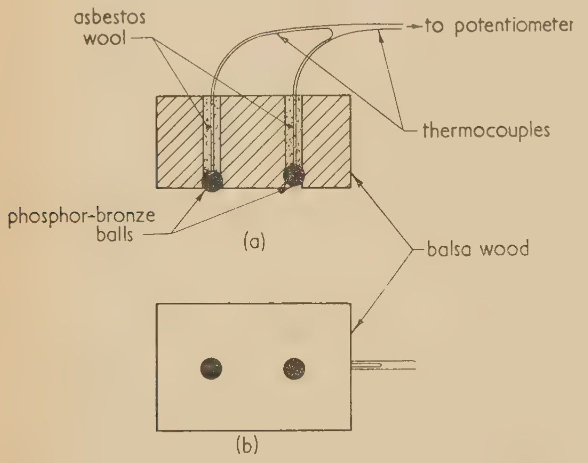

Fig. 1. Diagram of thermal comparator No. 1

(*a*) side view; (*b*) base view.

For the first set of measurements the thermal comparator embodying balls of 5/16 in. in diameter was placed in an oven controlled at 70° C and left to attain equilibrium. This was indicated by the reading of the differentially connected thermocouples being zero, or within a few μV of this value. Meanwhile the samples to be tested had been placed in position on an insulating blanket and allowed to come into equilibrium with the room.

The first materials to be tested are detailed in Table 1.

Table 1. *Rods tested by thermal comparator No. 1*

Material	*Description*	*Thermal conductivity (Jcm/cm² s °C)*
Copper	High purity ingot, 2½ in. diam.	3·94 (assumed)
Aluminium	Super-pure, 1 in. diam. bar	2·39
Iron	Armco, 1 in. diam. bar	0·73
Alloy steel	0·3 C, 3·4 Ni, 0·8 Cr: 1 in. diam. bar	$0{\cdot}34_3$
Alumina	Commercial 1 in. diam. bar	$0{\cdot}18_8$
High alloy steel	0·49 C, 1·9 Si, 16·75 Cr, 36·5 Ni; 1 in. diam. bar	0·11

Apart from the assumed value for the copper ingot the thermal conductivity values given in the last column had been obtained as the result of careful determinations on the same specimens. A small amount of extrapolation was, however, involved in some instances as the lowest temperature of these measurements was often of the order of 40° C. The 1 in. bars were all tested on the machined curved surfaces and the copper ingot was also tested on the curved surface which was as cast and fairly smooth.

In making a test, the thermal comparator was remove from the oven and quickly held with the one ball in stead contact with one of the test surfaces. The initial "zero reading of the differentially connected thermocouples ha been noted and subsequent readings were taken every 10 after contact had been established. The differential therma e.m.f. increased with time, owing to the more rapid coolin of the contacting ball, at first approximately linearly an then more slowly. In these particular tests the relativel linear rate of change lasted for about 20 s and it was no necessary for any one test to last more than 10 or 20 Some typical curves obtained at this stage from measurement with the comparator applied to various materials and whe freely cooling in air are plotted in Fig. 2.

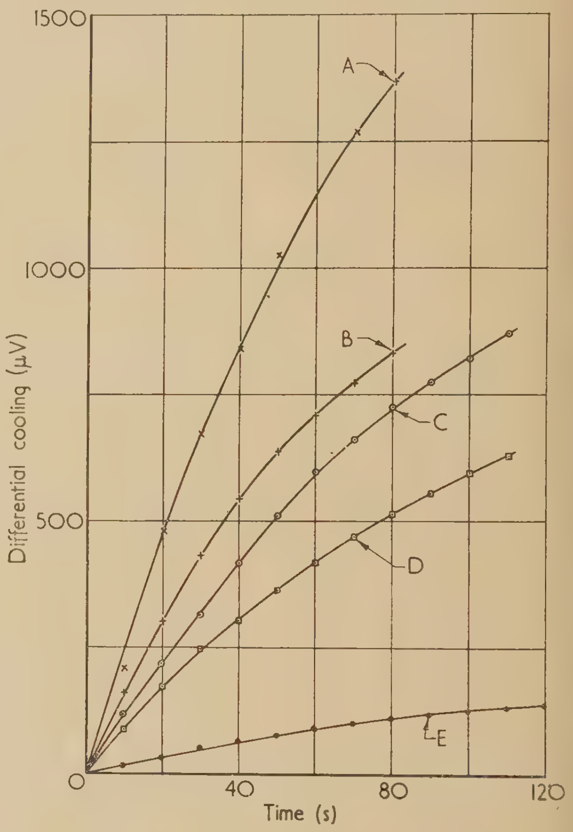

Fig. 2. Typical curves obtained from measurements with thermal comparator No. 1 applied to various materials and when freely cooling in air

A, aluminium; *B*, iron; *C*, alloy steel; *D*, high alloy steel; *E*, air.

In Fig. 3 the known thermal conductivity is plotted ordinate and the initial rate of cooling as determined by th differential thermocouple e.m.f. developed 10 s after makin contact as abscissa. The points are seen to lie reasonab well in a smooth curve. The shape of this curve suggeste that the square root of the thermal conductivity should plotted as ordinate. This has been done in Fig. 4 and th experimental points then show a surprisingly good fit to straight line. It will be noted that the air cooling rate w 2·5 μV/s and that as the thermal conductivity decreased a factor of 36 from that of copper to the high alloy steel th differential rate of cooling decreased from 25·8 to 8·8 μV/s

Using another thermal comparator, No. 4, which was fitte with two ¼ in. diameter phosphor-bronze balls, a series

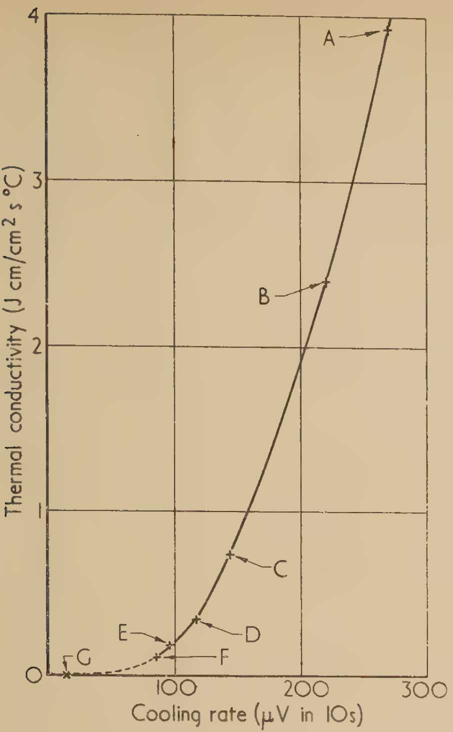

Fig. 3. Thermal comparator No. 1 applied to rods. Initial rate of cooling plotted against thermal conductivity

A, copper; *B*, aluminium; *C*, iron; *D*, alloy steel; *E*, alumina; *F*, high alloy steel; *G*, air.

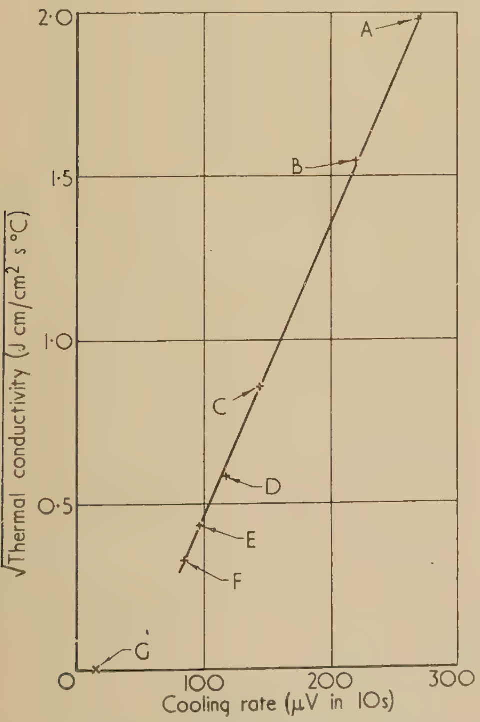

Fig. 4. Thermal comparator No. 1 applied to rods. Initial rate of cooling plotted against the square root of the thermal conductivity

A, copper; *B*, aluminium; *C*, iron; *D*, alloy steel; *E*, alumina; *F*, high alloy steel; *G*, air.

tests was made on materials of lower thermal conductivity. In this instance the test samples were in the form of lapped disks, and their thermal conductivities had been measured in a disk apparatus. The oven temperature was 61° C. Details of these samples are given in Table 2.

Table 2. *Disks tested by thermal comparator No. 4*

Material	*Description*	*Thermal conductivity (Jcm/cm² s °C)*
High alloy steel	0·49 C, 1·9 Si, 16·75 Cr, 36·5 Ni, 1 in. diam., ¼ in. thick	0·11
Quartz (⊥ to axis)	1⅜ in. diam., ¼ in. thick	0·067
Fused silica	3 in. diam., 3/16 in. thick	$0{\cdot}013_8$
Borosilicate glass	3 in. diam., ¼ in. thick	$0{\cdot}011_7$
Bonded mica	3 in. diam., 3/16 in. thick	$0{\cdot}007_5$
Polythene	3 in. diam., 7/32 in. thick	$0{\cdot}0033_5$
Plasticized P.V.C.	3 in. diam., ¼ in. thick	$0{\cdot}002_1$
Expanded ebonite	3 in. diam., 5/16 in. thick	$0{\cdot}0004_2$

The results for these tests are similarly plotted in Fig. 5 from which it will be seen that, despite the wide range of the present thermal conductivity values, the points again conform closely to a straight line. At this stage a comparator fitted with ⅛ in. diameter balls was tried, but the rate of cooling proved inconveniently large and the tests with this comparator were discontinued. Probably a smaller initial temperature differential should have been used in this instance but this has not yet been tried.

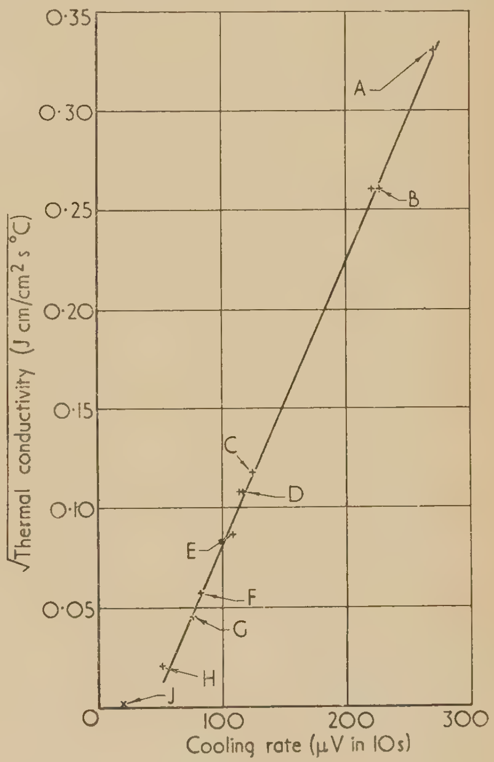

Fig. 5. Thermal comparator No. 4 applied to disks. Initial rate of cooling plotted against the square root of the thermal conductivity

A, high alloy steel; *B*, quartz; *C*, fused silica; *D*, borosilicate glass; *E*, bonded mica; *F*, polythene; *G*, plasticized P.V.C.; *H*, expanded ebonite; *J*, air.

This dependence on thermal conductivity calls for comment. Dependence on thermal diffusivity $k/\rho c$, where k is thermal conductivity, ρ the density and c the specific heat, is normally to be expected in variable state heat flow problems. However, k still remains the predominant variable, for whereas its values cover a 1 : 36 range for the materials listed in Table 1, the corresponding range for ρc is only 1 : 1·6. There are, however, definite indications from the present results that plotting against $\sqrt{k}$ gives the best correlation. Had thermal diffusivity been plotted instead of thermal conductivity the point for aluminium would be displaced on the high diffusivity side. Quartz would also behave anomalously, since its thermal diffusivity is comparable with that of the high alloy steel.

In the immediate region of the contact it would seem that the variable-state regime is of very short duration, and that the main heat flow occurs under relatively steady state conditions.

CONSIDERATION OF INFLUENCE OF APPLIED PRESSURE

The foregoing results had all been obtained with the thermal comparator held in contact with the test sample by one operator who had started a stop-watch on making contact, and the potentiometer reading was noted by a second operator just 10 s later. Under these conditions the degree of reproducibility in the results was surprising. The pressure exerted by the ball on the surface and the actual surface finish would both be expected to influence the contact and therefore the rate of cooling. Some further tests showed that when the tests were made with one comparator used under comparable conditions the cooling rate for a plane lapped surface of the high alloy steel was about 25% greater than for the machined curved surface of the 1 in. diameter rod of this steel.

In order to obtain information on the effect of applied load, known weights were added to the block and the loaded con parator allowed to rest in position. Measurements usir light loading proved difficult owing to some position control exerted by the attached thermocouples. Anoth unit, No. 5, was constructed using 42 s.w.g. thermocoup wires and stability was improved by providing a three-poi contact. To achieve this two pins' heads and the contacti ball were arranged to be in a plane parallel to the base of t block at spacings of about 1 in.

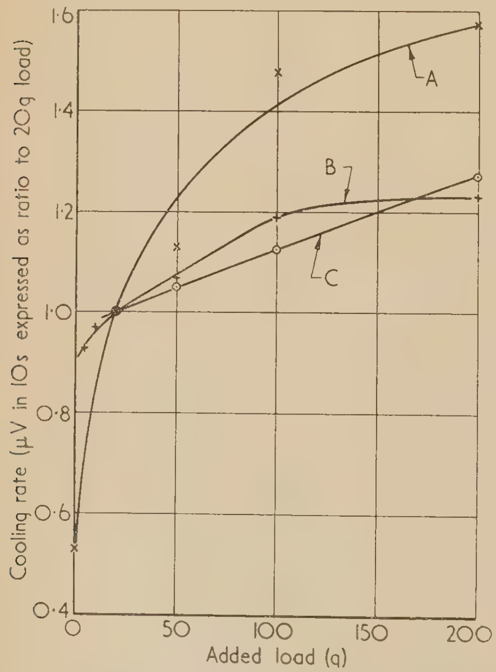

Fig. 6. Effect of load on cooling rate when thermal comparator No. 5 is applied to various surfaces

A, lead; *B*, alumina; *C*, brass.

The influence of loading can be seen from Fig. 6 whic shows the cooling rates obtained when thermal comparat No. 5, plus a specified load was applied to three plane su faces, brass, alumina and lead. The cooling rates are express as ratios to the rate with a 20 g load. For brass a line increase in cooling rate accompanied the increase in load u to 200 g, whilst for alumina a decreasing rate of increase observed beyond 100 g load. The two sets of data ar however, of comparable magnitude and suggest that defo mation of the ball may be the primary variable which modifying the area of contact. With lead, however, th dependence on loading is much more marked and this presumably accounted for by the softness of the lead.

MEASUREMENTS MADE UNDER CONSTANT LOA

Fig. 7 shows the results of measurements made with th comparator plus a load of 100 g when heated to 56° C a applied to the plane lapped surfaces of materials coverin 1140 : 1 range of thermal conductivities. Plotting cooli rate against the square root of the thermal conductivity again seen to give a good linear correlation over the ra from aluminium to the high alloy steel, but the poorer co

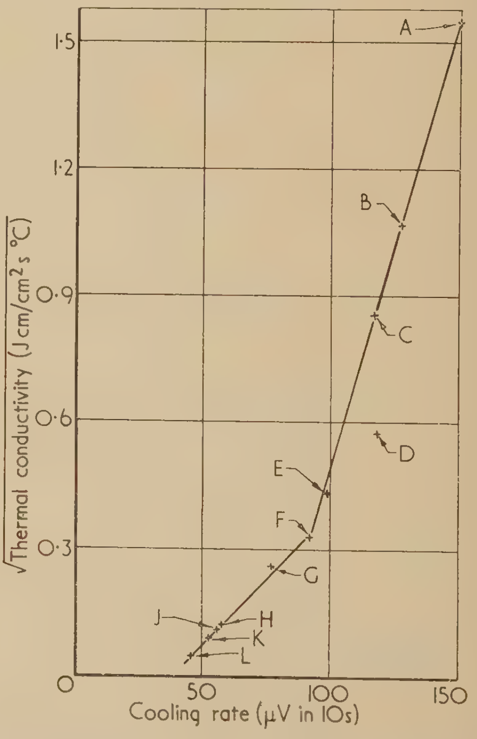

Fig. 7. Thermal comparator No. 5 loaded with 100 g weight. Initial rate of cooling plotted against the square root of the thermal conductivity

A, aluminium; *B*, brass; *C*, iron; *D*, lead; *E*, alumina; *F*, high alloy steel; *G*, quartz; *H*, silica; *J*, borosilicate glass; *K*, bonded mica; *L*, plasticized P.V.C.

tors are now seen to be on a line of lower slope, or possibly re is a gradual curvature at the low conductivity end. A asurement on lead was included and this point is seen to displaced on the high-rate-of-cooling side of the line ich suggests that the degree of loading is too great in this tance.

These tests showed that when the comparator was held in ntact the force had been equivalent to a load of about 100 g.

EPS TAKEN TO INCREASE SPEED OF SUCCESSIVE MEASUREMENTS

Although the actual observations of the rate of cooling ed only occupy 10 to 20 s, as many minutes are required er the thermal comparator is returned to the oven before insulated balls again reach a temperature approximating that of the oven. Earlier work had shown that consistent ults were obtained if the initial temperatures of the two lls differ by up to 0·25° C, ±10 to 20 μV, and an appro- ate correction is made to the reading at 10 s. Even so, ere is need for the rate of heating between tests to be celerated.

Work has been commenced on a thermal comparator in ich a few turns of fine wire have been wound on the con- cting ball so that this ball can be electrically heated for a ort time to bring it to approximately the required tem- rature. By this means approximate equilibrium at the en temperature is attained in well under a minute. This odification enabled six measurements to be made on a brass pped surface within a matter of 16 min, the values obtained r the cooling rates being 132, 132, 130, 132, 128, and 7 μV in 10 s, which is equivalent to derived thermal conduc- ities ranging from 1·08 to 0·9 Jcm/cm^2 s °C. This aspect the work shows promise but is still in its early stages.

DEMONSTRATION EXPERIMENTS

A somewhat different test procedure has been adopted recently when demonstrating the thermal comparator to groups of people. The leads from the pair of differentially connected thermocouples have been connected to a micro-voltmeter. This instrument had a scale with a central zero and gave full-scale deflexions of ±5 cm for ±100 μV. A knob adjustment was incorporated for bringing the pointer to zero. This adjustment was made just before removing the comparator from the oven, a stop-watch was started as contact was made and stopped after the pointer had moved to a predetermined reading for which a curve connecting time with thermal conductivity had been obtained. Current from a small dry cell was used to speed up the return of the pointer to zero after putting the comparator back in the oven.

SOME POSSIBLE APPLICATIONS OF THE THERMAL COMPARATOR

1. *Thermal conductivity determinations.* From the results of the measurements that have been plotted in Figs. 4, 5 and 7 it is clear that the instrument has possibilities for the determinations of the thermal conductivities of solids in terms of the known values for at least two calibrating materials. Knowledge of the probable accuracy, however, is still required, as well as rather more definite information as to the extent to which the values are likely to be influenced by the condition of the test surface.

In order to answer these questions in the case of metals tests have been made on a large number of disks prepared from rods for which thermal conductivity determinations had been made at temperatures of about 50° C and upwards.$^{(4, 5)}$ Each disk was 1 in. in diameter and $\frac{3}{8}$ in. thick;

Table 3. *Thermal comparator No. 6 used for thermal conductivity measurements on a number of alloy disks*
(Thermal conductivity in Jcm/cm^2 s °C)

Description of disk	*Known thermal conductivity*	*Measurements made on lapped surface*			*Measurements made on machined surface*		
		Cooling rate (μV *in* 10 *s*)	*Derived thermal conductivity*	*Difference* (%)	*Cooling rate* (μV in 10 *s*)	*Derived thermal conductivity*	*Difference* (%)
luminium, S.P.	2·39	160	*	—	—	—	—
% Aluminium	2·26	157	2·23	−1·3	140·5	*	—
l alloy No. 1	1·84	149·5	1·84	0·0	134	1·86	+1·1
l alloy No. 2	1·77	149	1·81	+2·3	134	1·84	+4·0
iduminium 100	1·59	144	1·59	0·0	126	1·46	−8·2
l alloy No. 3	1·48	142	$1{\cdot}48_5$	+0·3	126	1·46	−1·3
g alloy No. 1	1·28	137	1·28	0·0	122	$1{\cdot}26_5$	−1·2
g alloy No. 2	1·19	135	1·19	0·0	121	$1{\cdot}20_5$	+1·3
g alloy No. 3	1·10	132·5	1·11	+0·9	118	1·09	−0·9
g alloy No. 4	1·02	130	$1{\cdot}00_5$	−1·5	117	$1{\cdot}04_5$	+2·5
rmco iron	0·73	122·5	*	—	109	*	—
eel No. 1	0·64	119	$0{\cdot}63_5$	−0·8	106	$0{\cdot}62_5$	−2·3
g alloy No. 5	0·57	117	0·58	+1·8	104	0·57	0·0
g alloy No. 6	$0{\cdot}52_5$	115	$0{\cdot}52_5$	0·0	102	0·51	−2·8
eel No. 3	0·52	115	$0{\cdot}52_5$	+1·0	101	0·48	−7·7
eel No. 6	0·48	113	0·47	−2·0	101	0·48	0·0
eel No. 8	0·45	111	$0{\cdot}42_5$	−5·5	100	$0{\cdot}45_5$	+1·1
eel No. 20	0·43	111	$0{\cdot}42_5$	−1·2	99	$0{\cdot}42_5$	−1·2
eel No. 10	$0{\cdot}34_7$	108	$0{\cdot}35_1$	+1·2	97	$0{\cdot}36_5$	+5·2
eel No. 12	$0{\cdot}33_3$	107	$0{\cdot}32_8$	−1·5	95	$0{\cdot}32_8$	−1·5
eel No. 16	$0{\cdot}27_2$	103	0·26	−4·4	93	0·28	+2·9
eel No. 18	$0{\cdot}24_7$	102	$0{\cdot}24_3$	−1·6	92	0·25	+1·2
eel No. 14	$0{\cdot}13_4$	96	$0{\cdot}14_2$	+6·0	86	*	—
igh alloy steel	0·11	93	*	—	—	—	—

* Calibration point.

one plane surface was lapped to a smooth finish and the other was in the as-machined state.

When making each test the disk was inserted centrally in a 1⅛ in. diameter hole in the centre of a horizontal brass plate of equal thickness and resting on thermal insulation in equilibrium with the room. Thermal comparator No. 6 was heated in an oven at 68·5° C and, when a test was made, the ball made contact near the centre of the disk and the heads of the two pins rested on the brass. The comparator rested under its own weight and observations were made on a potentiometer in the original way.

For measurements on the lapped surfaces calibrations were obtained using the lapped disks of aluminium, iron and high alloy steel used previously, but for the machined surfaces the calibrations were made on iron and on two of the machined disks having extreme thermal conductivity values. The usual method of plotting gave good straight lines for each condition. Each surface was cleaned immediately before testing. Two tests were made for each calibration but only one reading was made in most other cases. The results obtained are set out in Table 3.

The test temperature has been assumed to be about 30° C and therefore a small amount of extrapolation has been necessary in obtaining the values given in column 2. The samples tested have included 5 aluminium alloys, 6 magnesium alloys and 9 steels, and, including the calibration points, a thermal conductivity range of about 20 : 1 has been covered.

From the entries in columns 3 and 6 it will be seen that the initial rate of cooling for the lapped surface is consistently about 12% greater than for the corresponding machine-finished surface. A change of this order would involve a large uncertainty in the thermal conductivity if only one calibration is used, but the derived values entered in the 4th and 7th columns have been evaluated from the respective calibrations for lapped and machine-finished surfaces and the differences between these values and the known values are then relatively small; within +6 and −5·5% for the lapped surfaces and within +5·2 and −8·2 for the machine-finished surfaces.

It is noteworthy that 80% of the derived values for the lapped surfaces and 58% for the machined surfaces are within 2% of the true values. An accuracy of this order is not much less than that obtainable by means of the time-consuming standard methods. Furthermore the thermal comparator should presumably be capable of greater accuracy when larger cooling rates are used and the mean value is taken of several observations. These results are in accord with those of Figs. 4 and 7, and it would seem that an accuracy of within about 6% is generally to be expected when a single thermal comparator measurement is made of the thermal conductivity of most of the metals and alloys so far tested, always provided that the calibration is made for surface conditions that are comparable as regards both geometric form and roughness.

At this stage attention should be drawn to the much larger error involved in the case of lead. It will be seen from Fig. 7 that use of the line appropriate to the other metals would give about twice the correct value for the thermal conductivity of this metal. There may be other instances of a similar kind, and, at this stage it will be necessary to proceed with caution before adopting the method for a metal or alloy for which it has not previously been shown to be satisfactory.

Figs. 5 and 7 would indicate that the thermal conductivities of many poorer non-metallic conductors should be measurable to about 10% so long as they are not too compressible, but no further tests in this field have yet been undertaken. For expanded ebonite the value is 50% high, which is not surprising for such an extremely poor conductor, and one in which the surface differs from the bulk of the material.

2. *Determination of surface finish.* In the foregoing section some consideration has been given to the influence of surface finish on the rate of cooling of the comparator. This has led to the conclusion that for any one material, for which the thermal conductivity would remain constant, the comparator might find an alternative use if it proved suitable for examining the degree of surface roughness.

In order to check whether this possibility was likely, four blocks of the same steel were prepared by the Metrology Division, N.P.L. A plane surface of each block had been ground to provide samples which were representative of fine rough and of two intermediate finishes. "C.L.A." determinations had been carried out on each surface in the Metrology Division and in Fig. 8 the results of these measurements expressed in microinches are plotted against the initial rate of cooling as determined by a thermal comparator when resting on the surface.

There will be seen to be a good correlation between the two sets of measurements, which suggests that the thermal comparator may also have uses in this alternative field, either for determinations of surface finish, or for checking that a required degree of finish has been attained.

It is hoped to undertake further experiments on this field. A comparator in which the phosphor-bronze balls are replaced by ball-bearings of hardened steel will be studied as the contacting ball might then be expected to retain a better surface finish. From Fig. 8, the comparator reading will be seen to be tending to become less sensitive to surface finish as rougher surfaces are tested. This may explain why thermal conductivity determinations on ordinary machine finished surfaces have proved practicable.

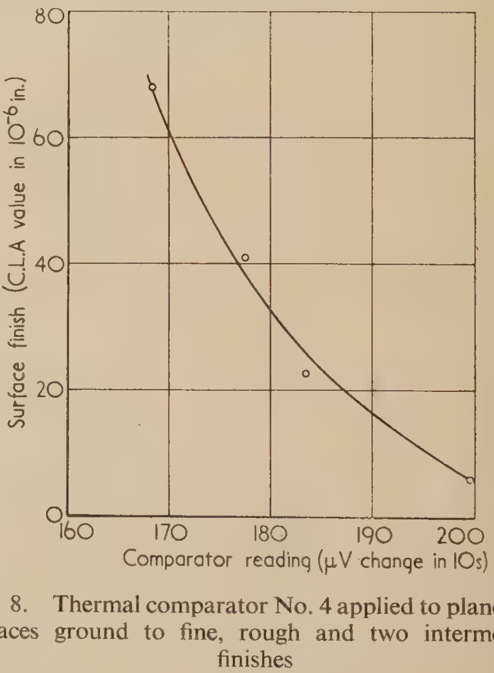

Fig. 8. Thermal comparator No. 4 applied to plane steel surfaces ground to fine, rough and two intermediate finishes

3. *Determinations of thickness and bonding resistances of surface deposits.* A further use considered for the thermal comparator has been the measurement of the thickness of surface deposits, such as electrodeposited metals, oxide films

even layers of paint. These deposits would need to differ thermal conductivity from the underlying material and to ve a negligible, or reproducible contact resistance with this se. Alternatively, for a constant thickness of a sufficiently in deposit, variations in this contact resistance might be udied. A problem of this kind was investigated some years o on specially prepared test surfaces by Powell and Hickan.(6) There was at the time some doubt whether these st surfaces were truly representative of the particular proiction problem or whether in the course of their preparation e bond between the two metals had been impaired. Had e present method been available it might have been usefully pplied as a means of resolving this element of uncertainty.

On the question of thickness, and, pending the provision suitable specimens with a deposit of known thickness, me somewhat analogous preliminary measurements have en made. Single sheets of aluminium foil having thickesses ranging from 0·000 03 in. (0·000 85 mm) to 0·0177 in. ·45 mm) have been interposed between a glass plate and e contacting ball of the comparator. The results of these easurements have been reproduced in Fig. 9 from which ere will be seen to be a good correlation between the known ickness of foil and the thermal comparator reading. To void further contraction of the vertical scale the point for e thickest foil has been omitted. For this foil of 0·45 mm ickness the comparator reading was 182 μV in 10 s, which only 13% greater than for the previous foil of about a uarter the thickness. This relatively small increase is no oubt associated with the approach towards the thickness which the cooling rate will become independent of thickness.

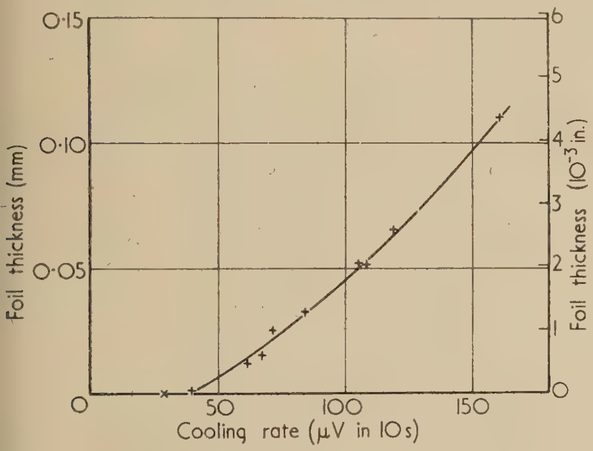

Fig. 9. Thermal comparator No. 4 applied to various thicknesses of aluminium foil on glass disk

The thickness at which this occurs is of importance in onnection with the application of the thermal comparator r thermal conductivity determinations, and is connected ith another aspect that still remains to be investigated. he minimum size of thermal conductivity sample for use ith any particular size of contacting ball. A thickness of e order of 1 mm appears likely to suffice.

4. *Identification and sorting of materials.* One of the main urposes to which non-destructive tests are applied is for lentifying or sorting materials. Although no specific appliations of this kind have so far been attempted it seems fairly ertain that there are many solid materials of similar appearnce which differ sufficiently in thermal conductivity for the iermal comparator to have useful applications in this field. ertain metals and alloys could clearly be differentiated in this way. In this connection tests at sub-normal temperatures may ultimately become of interest, for the thermal conductivities of many materials diverge as the temperature is reduced.(7, 8)

At normal temperatures the method might provide yet one further test for examining and checking the genuineness of precious stones. It should be simple to apply and free from any harmful effects.

5. *Examination of contacts.* Fig. 6 has shown how pressure can affect the rate of heat transfer between the ball and various materials. In the past the effective areas of such contacts have been derived in terms of electrical resistance measurements. The present technique would seem to offer a second method which might also be usefully applied.

SUMMARY

The foregoing account describes a very simple device, called a thermal comparator, which can be used for rapid measurements of thermal conductivities of solid materials. Calibration is needed using at least two materials of known thermal conductivity and of comparable surface finish. The prepared surface area on which contact is made need only be a few square millimetres in area. The only requirement of the specimen under test is that it should be in the same state of thermal equilibrium as the calibrating specimen. Room temperature has so far been adopted for this equilibrium state, but there would appear to be no reason for limiting the tests to this temperature and presumably tests at higher or lower temperatures will prove practicable. The size of the test specimen would appear to be immaterial, once a certain minimum size, yet to be determined, for each thermal comparator, has been exceeded. Thus the method could be used for tests on large ingots or even on built-in parts of a machine, say a crankshaft or cylinder block. All that is required is an exposed clean and representative surface to which the comparator can be applied and a similar calibrating surface.

Lead gives anomalous results, presumably accounted for by its softness and there may be other exceptions. An accuracy of ±6% is obtained in single tests made on several alloys of aluminium, magnesium and iron. The method is also applicable to poorer conductors, indeed the full range of solid thermal conductors can be covered with the one comparator. Other applications considered are, determination of surface finish, thickness of surface deposits and possibly an assessment of their thermal contact with the base material, and as a non-destructive method of sorting or identifying materials. The method also provides an additional means for investigating contacts between solids.

ACKNOWLEDGEMENTS

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A tunable infra-red interference filter

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An infra-red Fabry–Pérot interferometer working at very low orders as a tunable narrow band interference filter is described. The high reflecting surfaces are provided by germanium/cryolite quarter-wave stacks and the air gap between the surfaces may be varied to change the wavelength passed by the filter. It is shown that the luminosity of such an interference monochromator may be several hundred times higher than that of a prism or grating instrument of comparable size.

A monochromator in the form of a low order Fabry–Pérot etalon working as a tunable interference filter possesses certain advantages over grating and prism spectrometers. The luminosity as a function of resolving power may be several hundreds of times larger than for a prism or grating instrument of comparable size. Alternatively the instrument may be used at high orders as a high resolution system, when resolving powers greater than those of grating instruments may be obtained.(1) In either case auxiliary filtering is required to reject unwanted side bands and in the low-order case this has been achieved entirely with interference filters so that the instrument constitutes a true interference monochromator. Efficient high-reflecting stacks were constructed from quarter-wave films of germanium and cryolite: the high reflectance region extends over a wavelength region of about 25% of the mean wavelength. A schematic diagram of the interference monochromator is shown in Fig. 1.

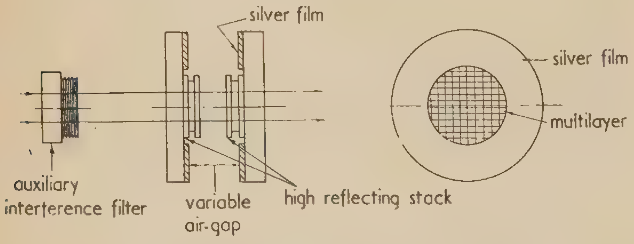

Fig. 1. Schematic diagram of interference monochromator

LUMINOSITY OF AN INTERFERENCE MONOCHROMATOR

We consider a low order Fabry–Pérot interferometer as a narrow band interference filter with an optical system as shown in Fig. 2. The source is circular and the aperture A restricts the radiation collected to that within a cone of semi-angle Φ. The form of the transmitted band as a function of wave number will then be found by summation of all the beams from normal incidence to Φ. The intensity $I(\omega$ transmitted at wave number ω is then given by(2)

$$I(\omega) = \frac{1}{\varepsilon}\int_{\Delta_0}^{\Delta_0+\varepsilon} \frac{d\Delta}{1 + F\sin^2\frac{1}{2}\Delta}$$

where
$$F = \frac{4R}{(1-R)^2}$$

and R is the reflectance of the stacks,

$$\Delta = 4\pi t\omega \cos\phi$$

and is the phase difference between successive beams at a angle of incidence ϕ for an interferometer with plate separa tion t,

$$\Delta_0 = 4\pi t\omega$$

and
$$\varepsilon = 4\pi t\omega(1 - \cos\Phi) \simeq 2\pi t\omega\Phi^2 \qquad (2$$

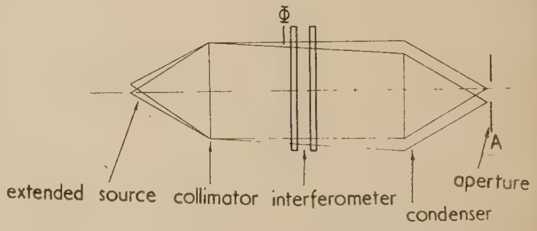

Fig. 2. Optical system for interferometer

In Fig. 3 a plot of $I(\omega)$ for the particular case whe $R = 0{\cdot}9$ and $\varepsilon = 0{\cdot}015 \times 2\pi$ is compared with the ban shape for the case of perfectly parallel radiation for which

$$I(\omega) = 1/(1 + F\sin^2\tfrac{1}{2}\Delta)$$

We note that the half-width for the "perfect" case is 0·034 2π as a fraction of an order and that if ε is approximatel equal to half this value the band is not unduly distorte The maximum is depressed by only 7% and the half-widt increased by 3%. The position of the peak is displaced to slightly larger wave number. The interferometer may thu be used in a beam of this convergence with little loss solution. Suppose now the interferometer uses this band scan an absorption spectrum and that the band half-width, , is small compared with the structure of the scanned ectrum. Ideally the band would be rectangular in shape id totally transmitting over $\delta\omega$; it would then have a trans-ission coefficient of unity. In fact the band shape is as own in Fig. 3 and the transmission coefficient τ_I will be ven by the average of $I(\omega)$ over $\delta\omega$:

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† Now at Royal Holloway College, University of London.

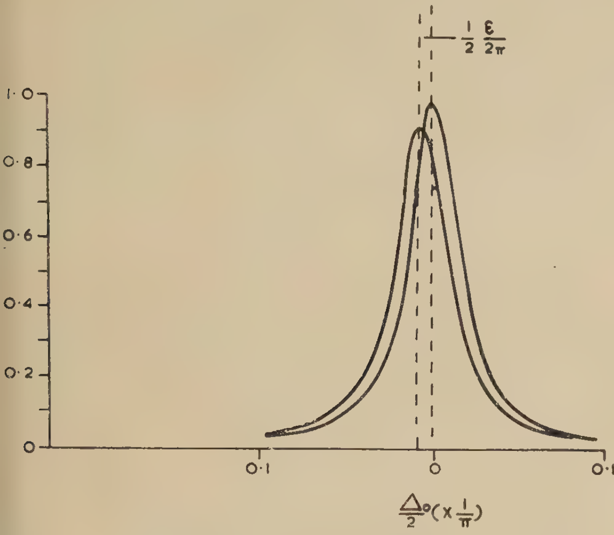

Fig. 3. Calculated effect on transmission bands of non-normal incidence. (Half-width as fraction of order = 0·034. Ratio of widths at half-height = 1·03)

$$\tau_I = \frac{1}{\delta\Delta_0}\int_{\Delta_0}^{\Delta_0+\delta\Delta_0} I(\Delta_0)d\Delta_0 \qquad (4)$$

here $I(\Delta_0)$ is found from equation (1). If ε is restricted so at $I(\Delta_0)$ is given approximately by the Airy curve, and $\delta\Delta_0$ taken as the half-width of the "perfect" system, then τ_I approximately 0·6 for the case considered above.

The total flux transmitted by the interferometer from a urce of luminance B is

$$F_I = B\tau_I T_I A_I \Omega \qquad (5)$$

here T_I is the value of transmittance at the peak of the and of the interferometer, A_I is the area of the interfero-eter and Ω is the solid angle of acceptance of the detector.

Now $\quad \Omega = \pi\Phi^2$ and $\Phi^2 \simeq \varepsilon/2\pi t\omega$ from (2);

us $\quad \Omega \simeq \varepsilon/2t\omega$

or the case considered, $\varepsilon = \delta\Delta_0 = 4\pi t\delta\omega$; also $2\delta\omega/\omega = 1/P$ here P is the resolving power of the interferometer. Hence $= \pi/P$ and $F_I = B\tau_I T_I A_I \pi/P$ which gives transmitted flux a function of resolving power. T_I can be adjusted to allow r the transmittance of any auxiliary filtering.

COMPARISON WITH PRISM AND GRATING INSTRUMENTS

Jacquinot(3) shows that the flux through a grating instrument ay be expressed as

$$F_G = (B\tau_G T_G \alpha_G A_G . 2\sin\Theta)/P \qquad (6)$$

where $\tau_G T_G$ are transmission coefficients of grating assembly,
α_G = angular height of exit and entrance slits (equal),
A_G = area of grating and
Θ = blaze angle of grating. This can be taken as equal to 30°.

The gain in energy of the interferometer over that of a grating of the same resolving power is

$$G = \frac{F_I}{F_G} = \frac{\tau_I T_I A_I \pi}{\tau_G T_G A_G \alpha_G} \qquad (7)$$

Now if $\quad A_I = A_G$ and $\tau_I = \tau_G$

then $\quad G = T_I\pi/T_G\alpha_G \qquad (8)$

α_G is usually $\sim$1/100 and T_I/T_G may lie between 0·1 and 0·5. Hence G will lie between $\sim$30 and 150 which is a very significant gain.

Jacquinot(3) has shown that a grating instrument has a luminosity at least five times higher than that of a prism spectrometer. The interferometer is thus capable of showing luminosities several hundred times higher than those of conventional prism spectrometers.

CONSTRUCTIONAL DETAILS

High-reflecting quarter-wave stacks of germanium and cryolite were deposited on fused quartz flats for an interferometer designed to operate at a wavelength of 2 μ. The layers, designated HLH, were deposited by vacuum evaporation and the thickness was controlled by continuously observing the variation in the reflection of monochromatic infra-red radiation of wavelength 2 μ. The reflectance was measured through the back surface of the flat and the monochromator used was a five-layer narrow band interference

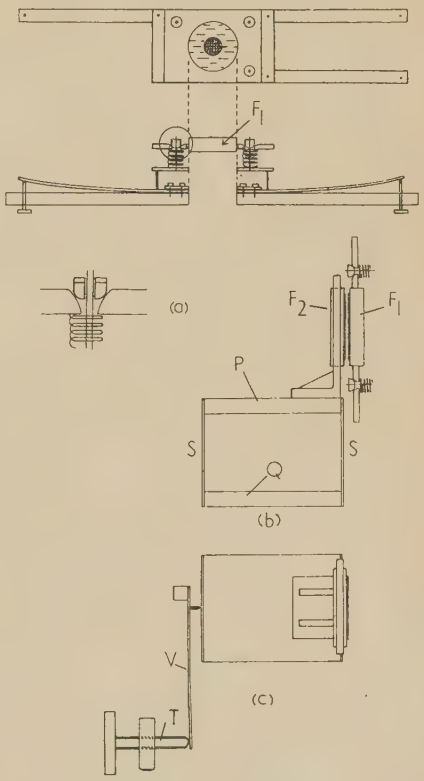

Fig. 4. The construction of the interferometer

filter in series with a seven-layer low-pass filter. These filters effectively isolate a band $\sim 0{\cdot}15\,\mu$ in width at $2\,\mu$.(5) A photoconductive detector with an 800 c/s amplifying system was employed. The high-reflecting stacks were 1 in. in diameter and a semi-reflecting silver film was deposited on the surrounding annulus, the central region being screened during the latter operation (see Fig. 1). The plates were subsequently adjusted for parallelism by observing Fabry–Pérot rings in the silvered annular region, using mercury light.

The method of mounting the plates is shown schematically in Fig. 4. Adjustments for parallelism are made on one of the interferometer plates F_1 [Fig. 4(*a*)] using an improvement of the method described by Heavens.(4) The other plate F_2 is mounted on a brass plate *P* [Fig. 4(*b*)] attached by two large square flat springs *S* to a second plate *Q*. By displacing *P* horizontally with respect to *Q* the separation between F_1 and F_2 can be varied, the plates remaining parallel to the necessary high degree of accuracy. Fine control of the spacing is effected by reduction of the motion of a 40 T.P.I. screw *T* [Fig. 4(*c*)] by a clamped spring *V*. For continuous scanning a barometer capsule is interposed between the screw *T* and the spring *V*. On evacuating the capsule completely, the plate separation varies by $4\,\mu$.

The apparatus is assembled in such a way as to minimize thermal expansion effects and insulated against high frequency vibrations by using massive parts and sorbo rubber pads. The precautions prove effective and the use of electric motors for spectrometer drives and choppers quite near the interferometer does not significantly disturb the instrument.

OPTICS

The optical arrangements are shown in Fig. 5. In position I, monochromatic mercury light is passed through the interferometer so that the plates can be made parallel. This adjustment is made by obtaining circular Fabry–Pérot rings with a plate separation of the order of $30\,\mu$. The gap is then reduced (using the normal movement) and the spacing estimated from the angular separation of the visible Fabry
Pérot rings. Fine adjustment of the spacing is made b
observation of the infra-red bands transmitted by the inter
ferometer.

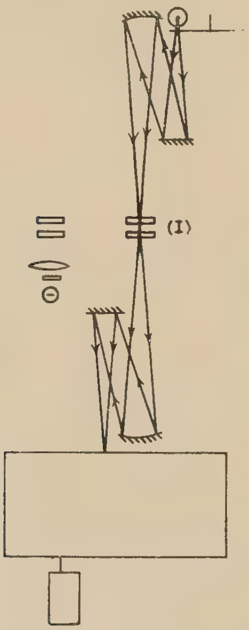

Fig. 5. Schematic diagram of interferometer layout

The interferometer is operated in a convergent beam o
semi-angle 3° for experimental convenience. This restrict
the order to not greater than 10 for a reflecting stack wit
$R = 0{\cdot}9$ or to not greater than 6 for $R = 0{\cdot}95$. At order
much greater than the above, this cone of incidence wi
significantly affect the band shapes. (The above method o
operation does not enable the maximum energy advantage
of the instrument to be obtained. For this, a parallel bea
must be employed as in Fig. 2.)

TESTS WITH THE INTERFEROMETER

The transmission bands of an interferometer with three
layer HLH stacks of germanium and cryolite were examine
by scanning the transmitted spectrum with a Leiss doub
prism monochromator. Fig. 6 shows the transmission of th
interferometer with the 7th order at $2\,\mu$. From the rati
of half-width to band spacing the effective reflectance of th
stacks may be deduced. The table shows the theoretica
and experimental values obtained.

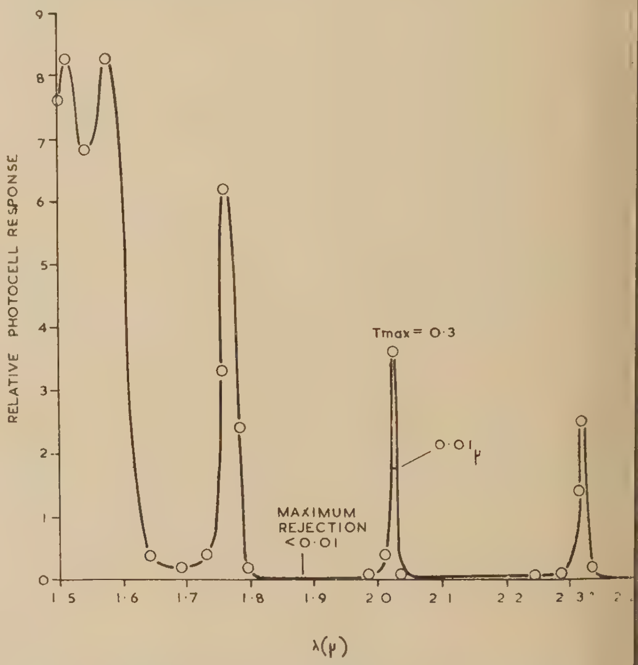

Fig. 6. Experimental transmission bands of 7th order
interferometer at $2\,\mu$ (designated HLH stacks)

Theoretical and experimental values of effective reflectance

	Half-width to spacing	*Effective reflectance*
Theoretical	1 : 65	0·95
Experimental	1 : 26	0·89

It should be noted that accurate measurement of the hal
width is affected by the resolution of the spectrometer an
that the instrument's limit was approached in this experimen
The experimentally deduced effective reflectance therefo
represents a lower limit and the stacks may in fact approac
the theoretical value more closely.

With the 7th order at 2 μ there is a separation of nearly ·25 μ between peaks and a half-width of 0·01 μ. On the iort wave side, the 8th order band at 1·76 μ shows a half-idth of 0·03 μ, the reflectance of the stacks having fallen 0·75 and at 1·65 μ the reflectance region of the stacks ends oruptly. The band at 2·32 μ with a half-width of 0·01 μ iows, however, that there is a usefully wide region over hich the band width varies insignificantly. The spacing of ie peaks is sufficient to allow the separation of any one of iem by auxiliary interference filters and the exact position f the pass band is then adjustable by varying the air gap. ig. 7 shows the transmission of the instrument, operating ith its 3rd order at 2 μ, in series with an auxiliary low-pass iterference filter.

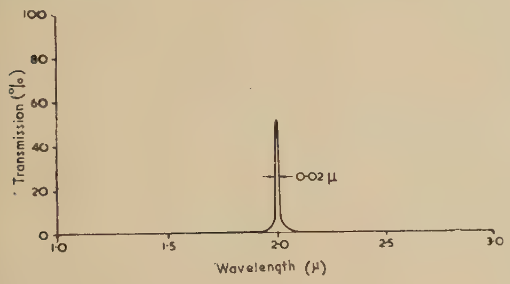

Fig. 7. Transmission of interferometer (3rd order) and cut-on filter over the range 1 to 3 μ

As a test on the fine control of the air gap, the 10th order and of the interferometer (this time with single layer gerianium stacks) was located with the prism spectrometer at μ. The interferometer band was moved to a slightly ifferent wavelength by increasing the air gap. The intererometer was then made to scan the spectrum transmitted y the prism spectrometer by a point-by-point adjustment of he fine control screw. The spectrum transmitted by the prism spectrometer was a band much narrower than the band of the interferometer itself so that the interferometer in fact measured its own band shape rather than the slit image. The half-width of the band of the interferometer was known to be 350 Å (from a previous prism scan). Two sets of readings were taken, with wavelength increasing and decreasing across the band. The results are shown in Fig. 8, and the curves show a total backlash of ~0·005 μ. This corresponds to a metrical backlash of ~0·017 μ in the air gap.

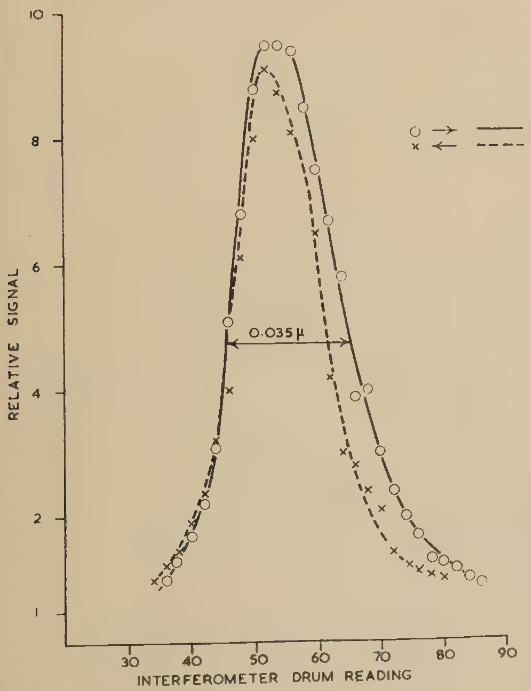

Fig. 8. Point-by-point scan by interferometer of Leiss monochromator output

As an indication of the potentialities of continuous scanning the interferometer was made to scan the slit image of the prism spectrometer and an absorption band of 1–2–4 trichlorobenzene. This was achieved by admitting air to the capsule (which had previously been evacuated) through a controlled leak. The exit slit of the prism spectrometer was fully open and with a narrow entrance slit a rectangular energy distribution 0·27 μ wide at 2 μ would be expected. The transmitted energy T is continuously recorded. The band obtained is shown in Fig. 9(*a*). A cell containing 1–2–4 trichlorobenzene was then placed in the beam and the scan repeated [Fig. 9(*b*)]. Hence the transmission of the 1–2–4 trichlorobenzene was deduced [Fig. 9(*c*)]. In this experiment the prism spectrometer was used merely as a convenient auxiliary filter and the scanning was achieved entirely by the interferometer; the instrument was in fact a scanning monochromator working entirely by interference methods. The above experiment was designed to show that scanning could be achieved over a relatively large wavelength range so that the scanning order was made low (i.e. 5th order). Consequently the resolution was of the same order as that of the prism instrument.

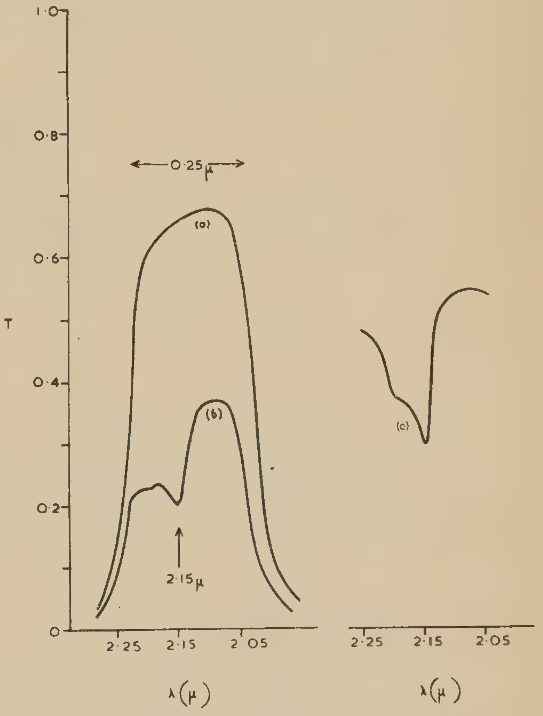

Fig. 9. Continuous scanning by the interferometer

CONCLUSIONS

A Fabry–Pérot interferometer with multilayer high reflectance stacks may be used at low orders as a variable interference filter for infra-red wavelengths. The pass band may be tuned to a given wavelength or scanned continuously over a range of 25% of the fundamental wavelength. The order of the interferometer was made sufficiently low to enable unwanted bands to be removed by multiple layer filters. The peak transmission of the interferometer together with its auxiliary filters is limited by losses due to absorption and scattering to a value of the order of 0·1–0·2. This value is likely to be a lower limit and improved evaporating techniques may be expected to raise it significantly. The realization of a monochromator relying only on interference films for its action allows the use of a circular radiation source and a circular cross-section for the beam throughout the optics. Under these conditions the energy advantages of the interferometer may be fully exploited and the luminosity may be several hundreds of times greater than can be obtained with conventional monochromators.

In this work the instrument was used with moderate resolution and high luminosity. It can however attain very high resolution by working at high orders, when the problems of auxiliary filtering are increased. A second etalon of lower order or a grating spectrometer may then be employed as the auxiliary. Improved scanning performance may be obtained if the auxiliary filter is ganged to the scanning band; the region which can be scanned is then increased to that over which the multilayer stacks reflect.

The instrument may be applied to the study of infra-re luminescence and recombination radiation from semiconducting materials. Near infra-red measurements are als used extensively in organic chemistry and the interferenc monochromator has application to both high resolution wor and routine measurements at fixed wavelengths. The techniques described may be extended to long wavelengths wher the use of thin slices of bulk material may be necessary du to deterioration of "thick" evaporated films.

ACKNOWLEDGEMENTS

The authors are indebted to Mr. H. Sixsmith for helpfu discussion and to the workshop staff of the University o Reading for the construction of the interferometer.

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The application of vacuum ultra-violet techniques to the continuous monitoring of trace concentrations of water in several gases

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A method for the determination of water in several gases is outlined in which use is made of the absorption bands of the water molecule in the 1200 Å region. A 20 Mc/s electrodeless discharge in hydrogen excites the 1216 Å Lyman α line very strongly and relatively free from neighbouring lines and bands. The radiation passes through the absorption cell, closed at both ends by lithium fluoride windows, on to the tungsten cathode of a photomultiplier which is insensitive to light of wavelength longer than 1400 Å.

1. INTRODUCTION

Recent improvements in the techniques of vacuum spectroscopy have resulted in substantial advances in the knowledge of atomic and molecular absorption spectra and the related absorption coefficients. This information, together with that obtained from the recent determinations of photoelectric quantum yields, has made it possible for methods using radiation below 2000 Å to be applied to the estimation of trace impurities in gases. The subject-matter of this report refers to one such case, namely the determination of water in nitrogen.

2. PRINCIPLE OF THE METHOD

The ultra-violet absorption spectrum of water vapour exhibits no appreciable absorption on the long wavelength side of 1850 Å; there are regions of continuous absorption between 1800 and 1300 Å, moderately intense in places, and a group of very intense bands between 1050 and 1250 Å.

Measurements of the absorption coefficients of water vapour over the range 1050 to 1850 Å have been reporte by a number of workers.(1, 2, 3) For the purposes of detectio and estimation it was considered that the best bands wer those at 1220 and 1120 Å respectively.

The 1220 Å band is apparently diffuse and structureless whereas the 1120 Å band possesses rotational structure. I practice this means that the absorption coefficient (reduce to N.T.P.) at the 1220 Å band does not depend upon th pressure, but does so depend in the case of the 1120 Å banc For quantitative work this leads to the utilization of th 1220 Å band (peak absorption coefficient 500 cm^{-1} at N.T.P. rather than of the 1120 Å band, although the absorptio coefficient is higher in the case of the latter (in excess c 600 cm.$^{-1}$).

The choice of band was eventually decided by a fortunat set of circumstances which permitted the elimination of monochromator. It is relatively simple to produce a dis charge in hydrogen which yields a great enhancement of th 1216 Å atomic line (first line of the Lyman series) which lie close to the peak of the 1220 Å H_2O band, with neighbourin

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oands of the hydrogen molecule only feebly present. Such s the case if hydrogen, flowing at a low pressure through a ube of glass or quartz, is subjected to electrodeless excitation oy means of a 20 Mc/s oscillator. Over the range 1550 to 1050 Å the light emerging from such a tube, closed with a ithium fluoride window (transparent down to 1050 Å) is found o be practically monochromatic in the 1216 Å line (Fig. 1).

Fig. 1. Spectrum of r.f. electrodeless discharge in hydrogen

f the light is allowed to pass through a column of gas which s transparent apart from any water it may contain, then any diminution in intensity of the radiation between 1050 nd 1500 Å will be almost entirely due to the absorption of he 1216 Å line by the 1220 Å band of water. The absorption coefficient involved here is high (390 cm^{-1} at N.T.P.).

Finally, recent work by Hinteregger and Watanabe(4) on photoelectric yields in the vacuum ultra-violet shows that he quantum yields of platinum, nickel and tungsten are quite high at 1216 Å and fall rapidly at longer wavelengths, becoming low at 1400 Å. Hence if a detector having a ungsten photo-cathode is used with the type of hydrogen discharge mentioned, the major fraction of the signal obtained will be due to the 1216 Å line, the intensity of which is sensitive o the partial pressure of water vapour present in the light path. The photo-cathode is quite insensitive to any near ltra-violet or visible radiations which may fall upon it.

3. APPARATUS

The apparatus first devised for this investigation is shown n Fig. 2, and consisted of the following components.

3.1 *Light source.* The light source originally used was a Pyrex vessel 3.5 cm outside diameter attached to a B34 male oint which was closed with a lithium fluoride window hrough a cylinder of thin walled silver cemented with molten ilver chloride.(5) Commercial tank hydrogen was drawn hrough the tube at 0·1 mm pressure by a rotary pump and egulated by a needle valve. The spectrum was excited by n r.f. oscillator working at a frequency of 16 to 20 Mc/s and theoretical output of 150 W. A circuit diagram of the scillator is shown in Fig. 3.

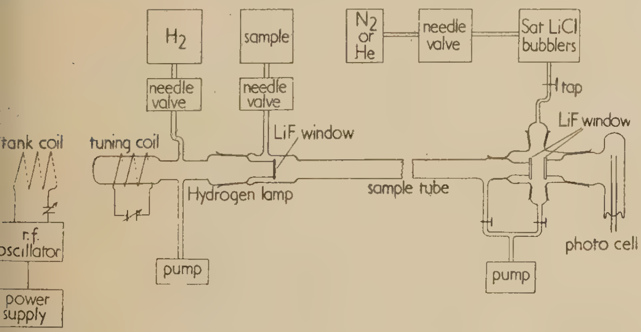

Fig. 2. Schematic arrangement of original apparatus

A hydrogen lamp was successfully sealed off after running continuously for 24 hours to outgas it. Although this type of source could be operated for several weeks before going "soft," it was finally decided that the original design, involving a dynamic system, was more expedient for long-term operation.

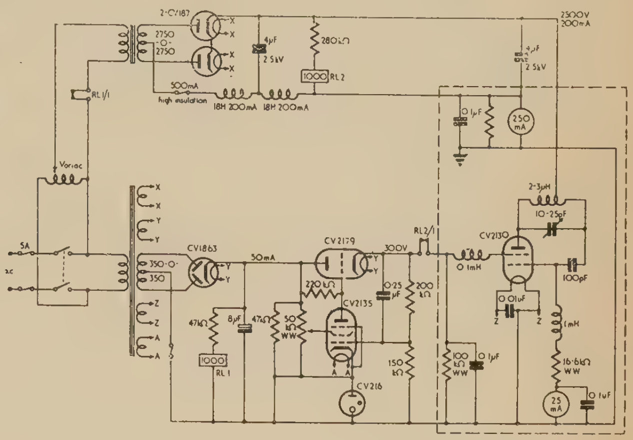

Fig. 3. R.F. oscillator and power supply

A considerable improvement in light intensity was effected by the use of a fused silica lamp and although this necessitated additional screening of the source to overcome the increased interference due to stray r.f. radiation, this design of lamp was much more efficient than its predecessors and was finally adopted.

3.2 *Absorption tubes.* It was convenient to have available two absorption tubes of different lengths (1 cm and 42 cm) and these were incorporated in series in one train, Fig. 2. Each cell was closed with a lithium fluoride window and the entire system was rendered vacuum tight by filling the ground glass joints with sealing wax. Both cells were linked to a pumping system so that they could be evacuated independently or have samples of gas drawn through either or both.

3.3 *Detecting system.* For the initial experiments a photocell was constructed in the following way. The cathode consisted of a piece of tungsten foil 1 in. square spot welded to a 2 mm diameter tungsten rod, whilst the anode was constructed from a 1 in. diameter ring of nickel wire welded to a similar rod. The electrodes were enclosed in a Pyrex envelope, the rods being sealed into position through a "pinch seal" of W_1 glass. A side tube closed with a lithium fluoride window(5) admitted radiation from the source. It was found necessary to use gas amplification at this stage and the cell was connected to a gas scavenger,(6) outgassed by thorough baking at 350° C and finally filled with helium at a pressure of 3 mm of mercury and sealed off. A potential of 150 V was applied to the cell and variations in the output on irradiation of the cathode were recorded with a sensitive valve voltmeter of conventional type. At a later stage a photomultiplier was incorporated in the recording system, see section (4.3).

4. EXPERIMENTAL

4.1 *Assembly and testing of the apparatus.* It was found that examination of the visible spectrum with a direct vision spectroscope gave a good indication of the vacuum ultraviolet emission, i.e. if the Balmer series were strong compared with the molecular bands, then the same condition applied to the Lyman series.

The output from a fully outgassed photocell was of the order of 10^{-10} A when the source was 42 cm distant with an intervening vacuum. Since this current was of the same magnitude as the grid current of the best readily available valve, it was clear that a simple and inexpensive electronic detector was not possible. Two alternatives were available, either, the photocell output could be detected with a quadrant electrometer or gas amplification could be used. The latter was adopted for early experiments, although some loss of linearity of response was to be expected under certain conditions.

The effect of various pressures of helium, argon and mixtures of the two in relation to stability, degree of amplification, saturation voltage and sensitivity were studied; it was concluded that a helium pressure of 3 mm of mercury and an applied voltage of 150 V yielded the optimum conditions, when an output of 5×10^{-9} A was obtainable.

A sensitive valve voltmeter, with negative feed back, was used as detector and a maximum sensitivity consistent with reasonable stability was obtained when the output from the photocell was applied across a 1000 MΩ load resistor. Simple qualitative experiments showed that the photocell responded to the presence of water vapour in samples of commercial tank nitrogen circulated through the longer of the absorption cells.

The stability of the light source was established over periods of 2½ hours. In the case of one particular lamp, a total of 60 operational hours resulted in a loss of sensitivity. This was associated with a loss in transparency of the lithium fluoride window, probably caused by bombardment with hydrogen ions and the gradual formation of F centres. The windows in other parts of the apparatus were unaffected.

4.2 *Initial quantitative experiments.* Initial quantitative experiments were directed to the measurement of the absorption coefficient of water vapour. Commercial oxygen-free nitrogen was first intensively dried by passing it through a close spiral immersed in liquid air and then passed through a series of Dreschel bottles immersed in a thermostat and containing a saturated aqueous solution of lithium chloride. The longer absorption cell was evacuated on a diffusion pump and the conditioned sample of nitrogen was pumped through the shorter cell of 1 cm path length, the pressure of the nitrogen being measured with a mercury manometer.

The vapour pressure of water above saturated lithium chloride has been established by a number of independent workers(7–10) and this information together with the experimental data enabled the absorption coefficient to be calculated. Results between 360 and 385 cm^{-1} N.T.P. were obtained and these were in reasonable agreement with the accepted value of 390 cm^{-1} N.T.P. Later experiments, involving the use of longer path lengths and lower concentrations of water vapour showed that the Bauger–Beer Law was not obeyed and theoretical absorption coefficients were not obtained in these circumstances, probably due to stray light or photochemical action.

The apparatus was then calibrated over the range 10 to 100 p.p.m. using the longer absorption cell (42 cm path length). Dry nitrogen was conditioned to known moisture contents by passage through a glass spiral containing ice at fixed temperatures within the range −24 to −60° C.

The results obtained were in good agreement with those obtained by the conventional "frost-point" method. The cell response Fig. 4 was again linear instead of exponential and this was attributed to stray light together with the effects of gas amplification.

4.3 *Improvement in sensitivity.* There was a requirement for the determination of water concentrations of order 0·1 p.p.m., in nitrogen at 760 mm of mercury pressure, and efforts were directed to the attainment of this order of sensitivity.

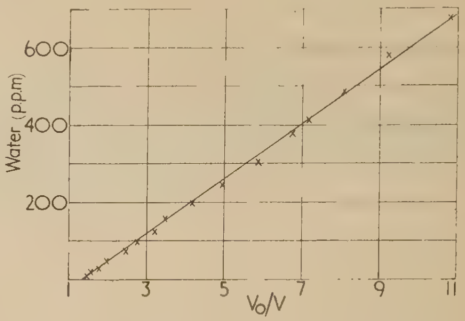

Fig. 4. Calibration curve with gas-photocell, 10–700 p.p.m. V_0/V range

In the case of hydrogen, nitrogen and the inert gases o mixtures of these, no appreciable absorption exists at 1216 Å and on this basis the detection limit of water vapour can be estimated as follows.

With a gas column x cm long containing water vapour a a partial pressure p mm of mercury, the emergent intensity of the 1216 Å radiation will be,

$$I = I_0 \exp(-390\, px/760)$$

from which $px/760 = (0 \cdot 43/390) \log_{10} (I_0/I)$
Assuming a measurement of I to an accuracy of 3% by the detector we may put

$$I = (97/100) I_0$$

when $$px/760 = 1 \cdot 5 \times 10^{-5}$$

If we take $x = 100$ cm as a convenient path length then

$$p/760 = (1 \cdot 5 \times 10^{-5})/100$$

The partial pressure of water vapour is then equivalent to 0·15 p.p.m., i.e. it should be possible to detect water to 1 p.p.m. with a column of 100 cm.

The apparatus was redesigned and a path length of the required order (actually 82 cm) was incorporated. This resulted in a four-fold diminution of light intensity and precluded the use of a photocell.

Recent work by Schwetzoff(11) on the construction of photomultipliers which function satisfactorily down to 2000 Å suggested the possibility of a similar detector for use at 1200 Å. A prototype photomultiplier was therefore developed in the laboratory from a beryllium-copper 14-stage particle counter made to the design of Dr. R. B. Owen of A.E.R.E., Harwell and modified by the addition of a tungsten photo-cathode. The photomultiplier was closed at the cathode end by a lithium fluoride window, and an E.M.I. type 16 pin photomultiplier base was sealed into the other to take the leads from the cathode and dynodes. This was continuously pumped, since the design of the particle counter did not permit permanent sealing off under vacuum.

A potential of 5 kV across a resistor chain of 10 MΩ per stage was found satisfactory, the output from the last dynode being connected to the valve voltmeter across a load resistor of 35 MΩ.

The stray r.f. experienced with the silica hydrogen lamp was readily picked up by the photomultiplier, and screening of the latter did little to improve stability. It was necessary to eliminate this interference at source, and a cabinet fabricated from heavy gauge aluminium was constructed to enclose the 20 Mc/s oscillator together with its power supply. The main leads to the power supply were also provided with filters. This screening was found to be satisfactory, and negligible r.f. pick-up on the photomultiplier was experienced.

Experiments with the photomultiplier showed it to have an output of 2×10^{-6} A representing a multiplication factor of 10^4 over the vacuum photocell.

It was found that the photomultiplier again failed to give an exponential response (Fig. 5) and empirical standardization appeared to be the most feasible approach to the problem.

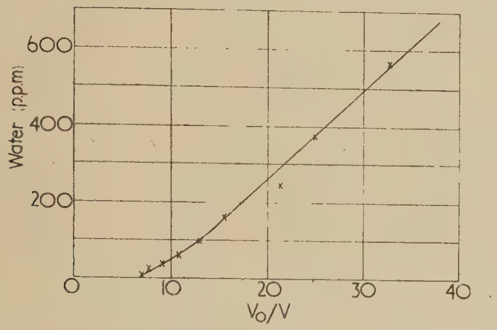

Fig. 5. Calibration curve with photomultiplier, 10–700 p.p.m. V_0/V range

The layout of the apparatus is shown schematically in Fig. 6. Oxygen-free nitrogen was bubbled through Dreschel bottles containing saturated lithium chloride solution and thence through two glass spirals and then to the longer absorption cell. The first glass spiral was maintained at −50° by means of Cardice and acetone to bring the water content down to about 40 p.p.m., thus allowing equilibrium to be more readily attained in the second spiral. The latter was controlled between −60 and −78° C again with Cardice and acetone giving a water concentration of 10·7 to 0·74 p.p.m. (by volume). The spiral was sealed directly to the absorption cell with glass tubing to minimize contamination which was found to occur with polythene.

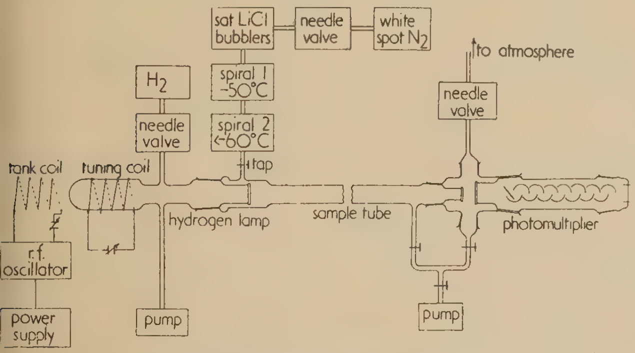

Fig. 6. Schematic arrangement of final apparatus

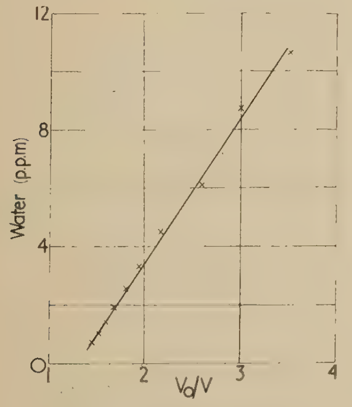

Fig. 7. Calibration curve with photomultiplier, 0–10 p.p.m. V_0/V range

The graph shown in Fig. 7 demonstrates the response obtained, each point being a mean of nine separate determinations recorded over a period of two weeks.

4.4 *Precision.* The water content of the nitrogen stream was adjusted to various levels by the method used for standardization and the results obtained are shown in the table.

Temperature of ice (°C)	*Water in nitrogen (p.p.m.)*	*Standard deviation σ*	*Coefficient of variation per determination*
−60	10·7	1·96	18·4
−64	6·1	0·53	8·7
−68	3·4	0·32	9·4
−72	1·9	0·29	15·7
−76	1·01	0·23	22·8

The figures quoted include any inaccuracies associated with measuring the temperature of the glass spirals containing ice. This fact probably accounts for the higher coefficient of variation at the 10 p.p.m. level, the change in vapour pressure of ice with temperature at −60° C being much greater than at lower temperatures.

5. APPLICATION TO OTHER PROBLEMS

Other possible uses for this technique arise where, although absorption by the gas to be monitored is not negligible it is nevertheless small compared with that of water; for example, in the case of water in oxygen, the absorption coefficient of oxygen at 1216 Å is approximately $0{\cdot}25\ \mathrm{cm}^{-1}$ at N.T.P. If we now limit the path length to 4 cm so that oxygen itself cuts the intensity to a steady I_0/e the type of calculation outlined in section 4.3 gives about

$$p/760 = 4 \times 10^{-6}$$

from which it is evident that in the absence of any perturbing effects arising from photochemical reactions following upon absorption of 1216 Å and lower frequencies by the oxygen molecules, it should be possible to monitor 1 part of water in 10^5 parts of oxygen. A similar calculation for water in carbon dioxide (absorption coefficient $\sim 2\ \mathrm{cm}^{-1}$ N.T.P.) gives a figure of 1 part in 10^4. It is of interest that the same apparatus could be used to measure methane concentrations to a similar order of sensitivity provided that the masking effects due to the simultaneous presence of water vapour could be neglected or allowed for.

A modification of the scheme could be used to monitor hydrogen sulphide in hydrogen, a matter of importance in connection with the hydrogen reduction of sulphides. H_2S has a strong absorption continuum around 2000 Å and by means of a spark between electrodes of aluminium or zinc it is possible to obtain a group of intense lines in this region well separated from the longer wavelength lines. As a detector a conventional photomultiplier with a layer of fluorescent material, such as sodium salicylate deposited on the outer surface of the envelope may be used. Rather than separate the required spectral region in the light source by a monochromator it was thought likely that the group of lines in the spark could be more efficiently isolated by means of focal isolation using a pair of quartz lenses. Preliminary experiments have confirmed this point.

6. SUGGESTIONS FOR FUTURE DEVELOPMENTS

Several possibilities exist for improving the performance and sensitivity of the apparatus.

6.1 A lithium fluoride lens would enable more light to be focused on the photo-cathode and allow the use of a simple gas amplified cell. So far grinding of such lenses has resulted in loss of transmission at 1216 Å and work is continuing on this problem.

6.2 A more compact instrument could be made by reflecting the radiation back upon itself to a recorder housed in a position adjacent to the source.

The use of an aluminized concave mirror in conjunction with a wider source would again result in focusing more light on to the photo-cathode, when a gas amplified cell could be used as recorder.

6.3 An even more compact instrument might be made by reflecting the radiation several times within a relatively short column by means of aluminium front surface mirrors, providing the reflectivity was of a sufficiently high order.

6.4 The use of a twin beam instrument coupled with a ratio recorder could be made the basis of an automatic recording apparatus for the continuous monitoring of gas flows.

ACKNOWLEDGEMENTS

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Dr. Frith (Meteorological Office) for helpful advice on the determination of frost points and for the loan of apparatus; the staff of the electronics section of the Woolwich Outstation A.E.R.E. who designed and constructed the oscillator and valve voltmeter; Messrs. A. Gunn and J. Piesse of the Chemical Inspectorate, Ministry of Supply, for glass blowing services and advice.

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An automatic adiabatic bomb calorimeter

By W. F. Raymond, M.A., A.R.I.C., R. J. Canaway, and C. E. Harris, The Grassland Research Institute, Hurley, Berks.

[*Paper received* 26 *June*, 1957]

The paper details the conversion of an existing isothermal bomb calorimeter to an adiabatic calorimeter with automatic control. Thermistors in the inner and outer vessels are included in two arms of an a.c. Wheatstone bridge: any rise in temperature of the inner vessel above that of the outer vessel results in phase reversal of the output voltage from the bridge, which operates a gas-filled tetrode controlling a 500 W heater in the outer vessel. A second tetrode, operated by off-balance voltage, controls a 1000 W heater in the outer vessel which accommodates the initial rapid temperature rise when the bomb is fired. The equipment has been found to be more rapid and much less tedious for routine use than the usual isothermal method. Determinations of heat content take approximately thirty minutes: the coefficient of variation of a single determination, with an average temperature rise of 1·9° C, is 0·34%.

he determination of calorific content is frequently required nutritional studies, and increasingly in the fuel and power dustries. However, while improvements have been made in e equipment used, and especially in the design of the comustion bomb, the technique of determination has changed ttle in the last forty years. In principle, the rise in temerature of the calorimeter vessel resulting from the combuson in oxygen of a known weight of substance is compared ith that produced by combustion of an equal weight of a bstance of known calorific value, generally benzoic acid.

The calorimeter vessel is surrounded by a larger vessel acket) of high heat content, which is assumed to remain othermal during the determination: as the temperature of e inner vessel rises it loses heat to the jacket at a rate proortional to the temperature difference between the two. y recording the rate at which the temperature of the inner essel falls after it has reached a maximum, the theoretical aximum temperature can be determined, either graphically(1) r by calculation.(2, 3) This process is tedious, as the operator as to take temperature readings at minute intervals over a eriod of 20–30 min, with subsequent calculation. The dvantage of an adiabatic system, in which the water in the uter vessel is heated up at the same rate as that in the inner essel, so that there is no heat transfer between the two essels, is obvious. Such a system was first used by ichards(4) for studying reaction kinetics, but the first adiaatic bomb calorimeter seems to have been described by aniels,(5) and has since been produced by the Emerson pparatus Co.(6) In this the operator observes thermometers the inner and outer vessels, and by a manual control raises e temperature of the outer vessel at the same rate as the ner vessel is heating up. The water in the outer vessel is eated by passing a current between two immersed electrodes, nd with practice the temperature difference between the ater in the two vessels can be kept below 0·02° C. Two evices for automatic control of adiabatic calorimeters were escribed by Richards and Osgood(7) and by Daniels.(5) The rst used a differential gas pressure switch, and the second sed thermocouples in the inner and outer vessels, both evices operating relays controlling heating of the outer cket. The second system has been further developed and sed in studies of heats of solution, etc. (e.g. by Urban,(8) nd by Ewing, Rogers, Miller and McGovern(9)). It does ot, however, seem to have been used in combustion caloriietry, probably because the low temperature response of ermocouples requires very sensitive control equipment hich would not seem suitable for routine calorimetric work.

Thermistors, which have a much higher temperature sponse, are more suitable for this purpose, and the present paper describes an automatic adiabatic control using thermistors: a principal aim in the design has been that it should allow conversion of existing bomb calorimeters. A commercial adiabatic calorimeter with automatic control has recently been demonstrated(10); in this the water in the outer vessel is heated by passing current through it, as in the system used by Daniels.(5) Sheathed heating elements have been preferred in the equipment described here.

CONTROL CIRCUIT

The control is based on an a.c.-energized Wheatstone bridge in conjunction with gas-filled tetrodes V_3 and V_4 (Fig. 1). Two arms of the bridge contain matched thermistors, one (T_1) in the inner (bomb) vessel, and the second (T_2) in the outer vessel. The output voltage from the bridge decreases as temperature equivalence between the two vessels is approached, and undergoes phase reversal when this point is passed. The tetrode V_3, being supplied with alternating anode voltage, is phase-sensitive and fires when the bridge

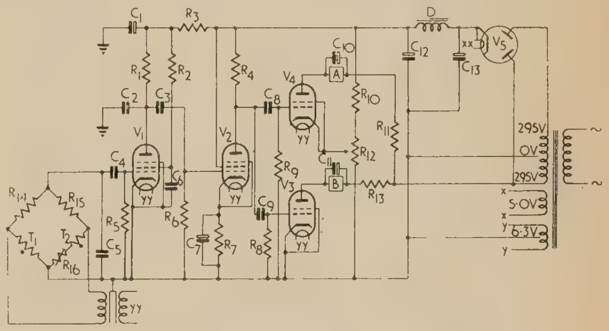

Fig. 1. Circuit diagram of control system

R_1 = 500 kΩ
R_2 = 2·2 MΩ
R_3 = 25 kΩ
R_4 = 10 kΩ
R_5 = 10 MΩ
R_6 = 1 MΩ
R_7 = 270 Ω
R_8, R_9 = 1 MΩ
R_{10} = 69 kΩ, 5 W
R_{11} = 10 kΩ, 2 W
R_{12} = 2·5 kΩ, w.w., variable
R_{13} = 10 kΩ, 2 W
R_{14}, R_{15} = 100 kΩ, w.w.
R_{16} = 100 Ω, w.w., variable (preset)

C_1 = 4 μF
C_2 = 0·002 μF
C_3 = 0·005 μF
C_4, C_5 = 0·01 μF
C_6 = 0·25 μF
C_7 – 50 μF

C_8, C_9 = 0·02 μF
C_{10}, C_{11} = 32 μF
C_{12}, C_{13} = 16 μF

V_1 = EF36
V_2 = SP61
V_3 = 2050
V_4 = 2050
V_5 = 5Z4

D = 7H
A = relay, 1000 Ω coil controlling 1000 W heater
B = relay, 1000 Ω coil controlling 500 W heater
T_1 = Stantel F 1512/300 thermistor in inner vessel (approximately 100 kΩ at 20° C)
T_2 = Stantel F 1512/300 thermistor in outer vessel

voltage applied to the grid is in phase with the anode supply, extinguishing when the bridge passes through balance; V_3 operates a relay B to a 500 W heater in the outer vessel. The second tetrode V_4 operates only when the off-balance voltage is relatively large (equivalent to a temperature difference of approximately 0·02° C, and determined by R_{12}) and controls a 100 W heater in the outer jacket. The total loading of these heaters is such that they are capable of heating the outer vessel at least as rapidly as heat from combustion in the bomb heats the inner vessel. The larger heater accommodates the initial rapid rise in temperature after the firing of the bomb, while the 500 W heater allows later response to small temperature differences without the risk of overshooting likely if the full heating load were applied.

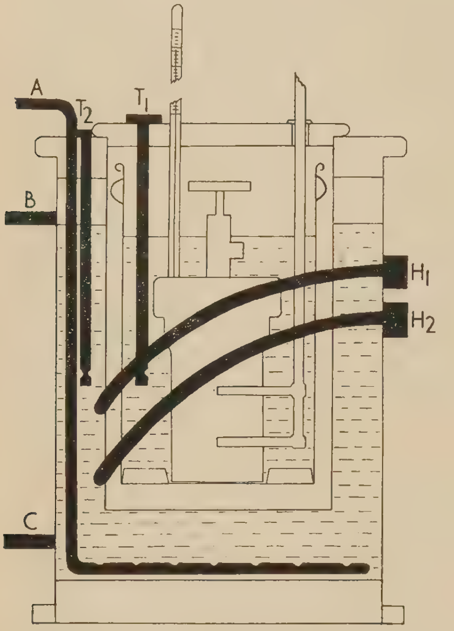

Fig. 2. Modifications to Mahler–Cook bomb calorimeter shown in black

A, cooled air bubbler to outer vessel; *B*, *C*, water overflow and inlet to outer vessel; T_1, T_2, thermistors in inner and outer vessels; H_1, H_2, terminal connexions from control to 500 and 1000 W heaters in outer vessel.

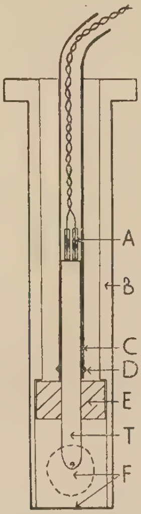

Fig. 3. Detail of thermistor units

A, Polyvinyl chloride tube covering soldered joints; *B*, Bakelite tube 10 in. long × ½ in. diameter; *C*, polyvinyl chloride tubing, bound to thermistor by wire at *D*; *E*, tight-fitting rubber plug; *F*, openings to water in vessel; *T*, thermistor.

The heater elements used (Backer ¼ in. Inconel, 20 W per inch) are bent so as to introduce heat as uniformly as possible into the water in the outer vessel, and the ends are taken through silver-soldered joints in the casing to terminal boxes for connexion to the control output leads.

Thorough mixing of the water is essential to avoid local overheating, and this is achieved by bubbling air up through the water from an annular perforated pipe resting on the floor of the outer vessel (Fig. 2). This air may be supplied by a compressor, in which case it will be warm, and must be cooled slightly before passing to the bubbler. Excellent mixing has been obtained by this system.

Construction of thermistor units. The constancy of the differential thermistor control depends on perfect electrical insulation of the leads from these units. This has been obtained by enclosing them in polyvinyl chloride tubing inside Bakelite probes (Fig. 3), which give mechanical protection. These are inserted through the lid of the calorimeter.

OPERATION

The required weight of water, at a temperature 1–2° C below room temperature, is weighed into the calorimeter vessel, and the outer jacket filled with tap water, which is generally well below room temperature. The bomb containing the weighed sample and oxygen is placed in the inner vessel and the lid placed in position: through this passes the thermometer for temperature measurement, stirrer, and thermistor T_1 (Fig. 2). After a period of stirring the control is switched on, bringing the water jacket up to the same temperature as the calorimeter vessel. The steady temperature in the inner vessel is recorded and the bomb fired. After a short delay the inner temperature begins to rise and the control switches on the 500 W heater, rapidly followed by the 1000 W heater. The latter heater is switched off whenever the temperature in the outer jacket tends to rise above that in the calorimeter vessel, and when the rate of temperature rise slows down only the 500 W heater is in circuit. Finally the inner temperature becomes steady, and the 500 W heater switches on only for short periods to make up heat lost from the outer vessel. In the present equipment (a modified Mahler–Cook calorimeter[11]), a steady temperature is reached within 13–15 min. No variation in this temperature is observed within the limits of precision of the mercury-in-glass thermometer used (N.P.L. calibrated every 0·5° C to ±0·002° C) during a subsequent period of 20 min, as long as the inner vessel is not more than 1–1·5° C above ambient.

With a greater difference than this there is a detectable loss of heat through the lid, stirrer, etc., and some temperature correction has to be made, in which case the advantage of adiabatic control is lost. To obviate this the Gallenkamp calorimeter[10] is fitted with a hollow lid through which water from the outer jacket is pumped, so keeping it at the same temperature as the inner vessel. However, with the present calorimeter and thermometer if the water weighed into the calorimeter vessel is below ambient temperature, no detectable error in measurement of temperature rises of 1·5–2° C has been found. If temperature rises greater than this or calorific values at higher temperatures have to be measured, an adiabatic lid must be fitted to the calorimeter.

TESTING OF THE EQUIPMENT

The time taken for a determination of calorific content was min, including changing the water in the two vessels tween determinations, but excluding the pelleting and eighing of samples. With an average temperature rise of 9° C, the coefficient of variation of a single determination the heat content of the bomb vessel, based on ten deterinations, was found to be 0·34%. The mean value of heat ontent was identical with that obtained by the isothermal ethod.

ACKNOWLEDGEMENTS

We should like to thank Dr. A. R. Meetham of the ational Physical Laboratory and Mr. C. Baker of the Fuel esearch Station for useful discussions on this problem, Iiss K. M. Wolton for assistance in calibration tests, and r. William Davies for his encouragement in the development this equipment.

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A lateral extensometer for the determination of Poisson's ratio of rock

By E. R. Leeman, M.Sc.(Eng.), and C. Grobbelaar, B.Sc.(Eng.), National Mechanical Engineering Research Institute, Pretoria, South Africa

[*Paper received* 27 *May*, 1957]

A lateral extensometer is described by which the lateral strain occurring in a cylindrical rock specimen subjected to a linear axial compressive load in a compression test, can be read or recorded continuously up to the point of fracture of the specimen. The lateral extensometer has been designed to operate in conjunction with a compressometer (described in a previous article) which measures the axial strain occurring in the specimen. The measuring element used in the lateral extensometer is a linear variable differential transformer and deformations of the specimen of the order of 1 μin. can be measured. The instrument has been designed in such a way that it suffers no physical damage when the specimen, to which it is attached, fractures. In fact, over 300 rock specimens have been tested using one of these instruments without its accuracy or mechanical condition having been seriously impaired.

a previous article⁽¹⁾ a description was given of a comressometer designed by the authors to measure axial comression strains in cylindrical rock specimens which were eing subjected to compression loading at a constant rate up the point of fracture. From the readings so obtained the oung's modulus of the rock specimens was determined.

This article describes a lateral extensometer which was eveloped for use in conjunction with the compressometer. his instrument measures the lateral strains in the rock pecimens and from the readings obtained, the value of oisson's ratio of the specimens is determined.

DESCRIPTION OF THE LATERAL EXTENSOMETER

The lateral extensometer was designed to meet the following quirements. It had to

(i) measure the lateral strains of cylindrical rock specimens in. in diameter with an accuracy of at least 5%;

(ii) be sufficiently sensitive to measure strains of 0·001%. On a diameter of 1 in., therefore, it had to be capable of measuring deformations of 10 μin. of the specimen;

(iii) have a measuring range of approximately 0 to 0·3% strain. On a diameter of 1 in., therefore, it had to be capable of measuring lateral deformations up to 3000 μin.;

(iv) measure strains continuously up to the point of fracture of the specimen and therefore had to be sufficiently robust to withstand the shocks resulting from the fracture of the many specimens to which it would be attached; and

(v) to operate in conjunction with the compressometer so that both Poisson's ratio and Young's modulus could be determined from each specimen.

All of these requirements were met in the lateral extensometer illustrated in Fig. 1. The instrument consists of a stainless steel frame *A* machined from the solid. Stainless steel was used on account of its rigidity (high Young's modulus). The non-magnetic properties of this material were also found to be an advantage in that magnetic interference effects on the linear variable differential transformer used were less than when ordinary mild steel was used. The instrument is clamped on the specimen *B* by means of the hardened steel clamping screws *C*. The ends of these screws are ground to a rounded conical point. The clamping pressure is provided by the spring clip *D*. The hinge *E* about which the two arms *F* and *G* pivot is formed by reducing the section of the extensometer ring at this point. It will be observed that a magnification of the displacement of the clamping screws of $\frac{a+b}{a}$ is obtained at the end of the measuring arms of the extensometer. With a magnification of 12 the measuring elements at the end of the arms were sufficiently sensitive to measure the lateral deformations of the specimens. In fact, with the instrument made deformations of 1 μin. could be read.

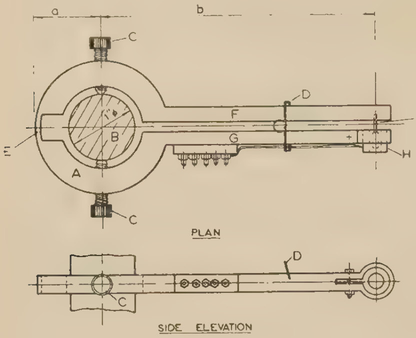

Fig. 1. The lateral extensometer

The measuring element *H*, which is used, is a linear variable differential transformer (l.v.d.t.) manufactured by Shaevitz Engineering, U.S.A., type number ML020. As shown in Fig. 2 it consists of three solenoidal coils M_1, M_2 and M_3 inside of which a small cylindrical core *K* is free to move. In the extensometer, the core *K* is attached to arm *F* and the coils to the arm *G* in such a way that the core can move freely inside the coils. The centre coil M_2 is connected to a stable high-frequency a.c. voltage V_1. When the core is in the centre of the coils the magnetic field of M_2 induces equal voltages in M_1 and M_3. Since coils M_1 and M_3 are connected in opposition the output voltage V_2 under these conditions will be zero. When the core is displaced, in the direction of M_1, say, the voltage induced in M_1 will be greater than that in M_3 and this will be reflected in the reading of V_2. The voltage V_2 varies linearly with axial displacement of the core and is not affected by small lateral displacements of the core.

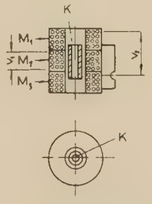

Fig. 2. The linear variable differential transformer

The calibration curve of one of the lateral extensometers in use is shown in Fig. 3, where the core displacement is plotted against output voltage V_2. In order to achieve the sharp change in direction of the curve near the zero it was found necessary to include a suitable harmonic filter and a compensating l.v.d.t. in the circuit. The final circuit used is shown in the diagram in Fig. 4, where *A* represents a constant voltage signal generator, *B* the measuring l.v.d.t., *C* the compensating l.v.d.t., *D* the harmonic filter and *E* a variable step amplifier which feeds into a vacuum tube voltmeter *F*.

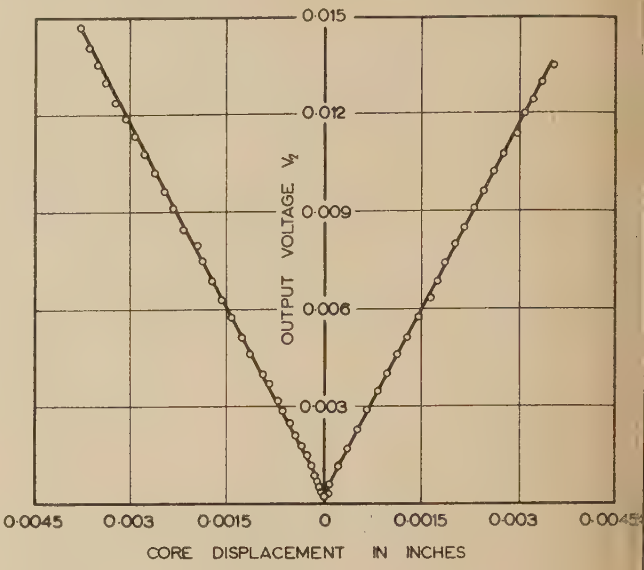

Fig. 3. Calibration curve

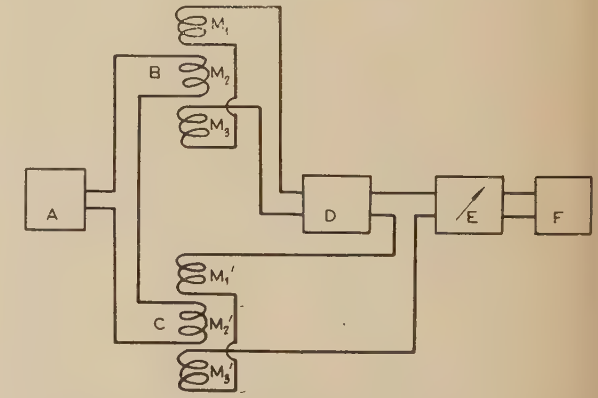

Fig. 4. The circuit diagram used for the lateral extensometer

A, constant voltage signal generator (7 V, 3 kc/s); *B*, measuring l.v.d.t.; *C*, compensating l.v.d.t.; *D*, harmonic filter; *E*, amplifier; and *F*, vacuum tube voltmeter.

The manner in which the lateral extensometer was made to operate in conjunction with the compressometer is illustrated in Fig. 5(*a*). It will be observed that the ring *C* in the original compressometer shown in Fig. 5(*b*) has been replaced by the lateral extensometer. The thickness *t* [see Fig. 5(*a*)] of the extensometer has been made such that when the clamping screws of the compressometer are in position on the specimen there is sufficient clearance between the extensometer and the compressometer rings *A* and *B* to avoid any interference between them.

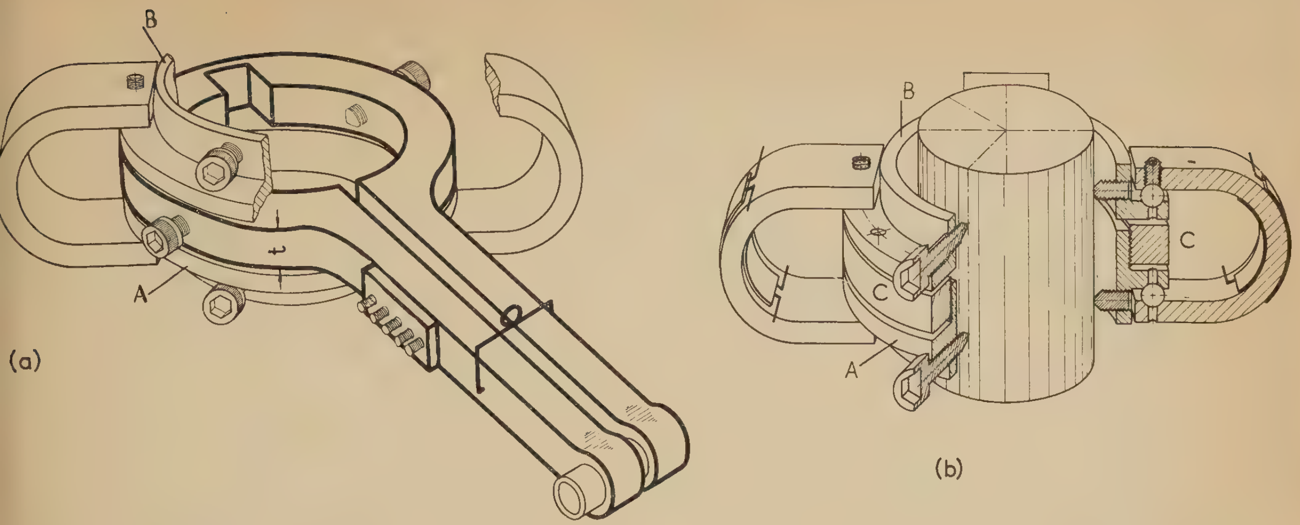

Fig. 5. (*a*) The lateral extensometer used in conjunction with the compressometer; (*b*) the original compressometer without the lateral extensometer incorporated

ENSITIVITY AND ACCURACY OF THE LATERAL EXTENSOMETER

In using the lateral extensometer, the amplifier is set at its aximum gain position at the beginning of the test so that specimen deformation of approximately 200 μin. gives a ll-scale deflection on the vacuum tube voltmeter. When e voltmeter needle reaches the end of its scale, the amplifier switched to half maximum gain. This brings the voltmeter back to half its full-scale reading and so another 200 μin. may be read. By repeatedly halving the amplification the range of the instrument is increased to 400, 800, 1600 and 3200 μin.

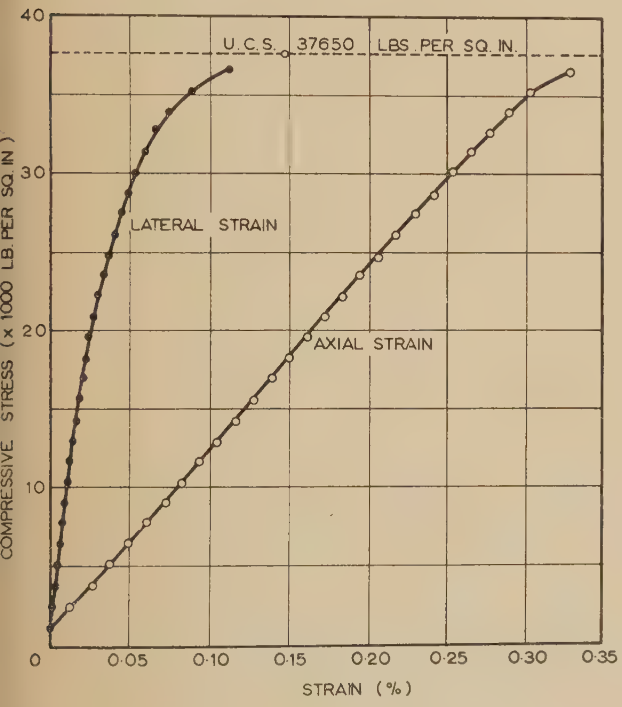

Fig. 6. Stress/strain curves for quartzite

The decrease in sensitivity so produced does not, however, have a serious effect on the determination of the "compressive stress/lateral strain" curves. It will be observed from Fig. 6, which is a typical curve from a specimen of quartzite, that the curve is not a straight line and that as the stress increases, the strain changes at a gradually increasing rate. Hence every time the sensitivity of the strain measuring instrument is halved the changes in strain for equal increments of compressive load are approximately doubled. The percentage accuracy of the lateral strain readings remains, therefore, approximately the same throughout the test.

In Fig. 6 is also shown the "compressive stress/axial strain" curve, which was obtained at the same time as the "compressive stress/lateral strain" curve, using the compressometer.

Slow changes in the characteristics of the electrical components necessitate occasional calibration of the lateral extensometer. Check calibrations on a steel specimen whose characteristics are accurately known are conducted after every twenty specimens are tested, however, and it is found that the instrument is consistently accurate to better than 5%. The design, furthermore, has been found to be sufficiently robust to withstand the shocks caused by the fracture of many specimens without causing physical damage to it.

ACKNOWLEDGEMENT

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A water-wave measuring apparatus

By A. Brebner, B.Sc.(Eng.), Ph.D., A.M.I.C.E.,* Engineering Department, University of Aberdeen

[*Paper received* 14 *June*, 1957]

Values are given for the electronic circuit required to detect, amplify and rectify a variation in resistance produced by fairly rapidly changing water levels on a pair of immersed probes, a situation met in the measurement of water waves in laboratory experiments. The accuracy of such an apparatus is checked and assessed by comparing with the usual pointer type of gauge instead of by further electrical means, and is well within the usual requirements for such experimental work.

In hydraulic models built to investigate wave or surge phenomena, and also in wave tanks, channels, etc., used with the same end in view, by far the most straightforward method of measuring amplitudes is by ordinary micrometer gauges, one for the crest and one for the trough. These have the great advantage of cheapness and of being readily calibrated to any datum—usually still water level.

However, important as the amplitude is, these gauges do not give the wave-form (nor the amplitudes with any great accuracy if the waves are irregular) and this may be equally as important, especially, for example, in wave channels where the end effects and reflexion have an influence on the wave behaviour and its effect on mass-transport, bottom velocity, etc.

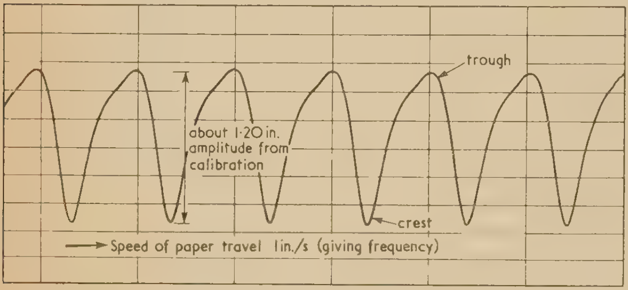

Fig. 1. Sample of record of wave-form from pen recorder

The apparatus described below is designed to give a continuous record of wave-form on the standard type of pen recorder, Fig. 1 showing a typical sample. It consists essentially of the following components.

(*a*) A beat-frequency oscillator with a variable output of up to 50 V at frequencies up to 20 kc/s. The high frequency serves as a carrier wave which is modulated by the low-frequency water waves.

(*b*) A detector circuit wherein the variation in water level at any section as a wave passes that section is measured by resistance change and thence by voltage change.

(*c*) An amplifier wherein this latter small voltage change is amplified and then rectified before being fed to the pen recorder.

(*d*) A pen recorder of the low-frequency type since it is seldom that water-wave frequencies of more than two or three per second are met in hydraulic work in the laboratory. (For higher frequency water waves the time constants in the diode rectification might require slight alteration.)

Items (*a*) and (*b*) are standard pieces of apparatus obtainable commercially, item (*d*) as used by the author being quick response recorder by Evershed and Vignoles Ltd. Items (*b*) and (*c*) are described more fully and illustrated in Fig. 2.

DETECTOR CIRCUIT

The output from the oscillator is fed into two 40 : 1 step-down screened transformers (Savage type 4P64.A) and thence into two identical circuits. The voltage tapped off each circuit can be varied within narrow limits by the 200 Ω variable resistances and balanced against each other by a valve voltmeter V_1 interconnecting these circuits. For approximately 20 V input from the oscillator approximately 0·5 V appears on each circuit, this voltage being achieved by the step-down and the position of the voltage tap. A low voltage of this order is desirable from a safety point of view since it is fed to the water. The high frequency (anything between about 2 and 20 kc/s) is used to minimize electrolysis and facilitate amplification and diode detection.

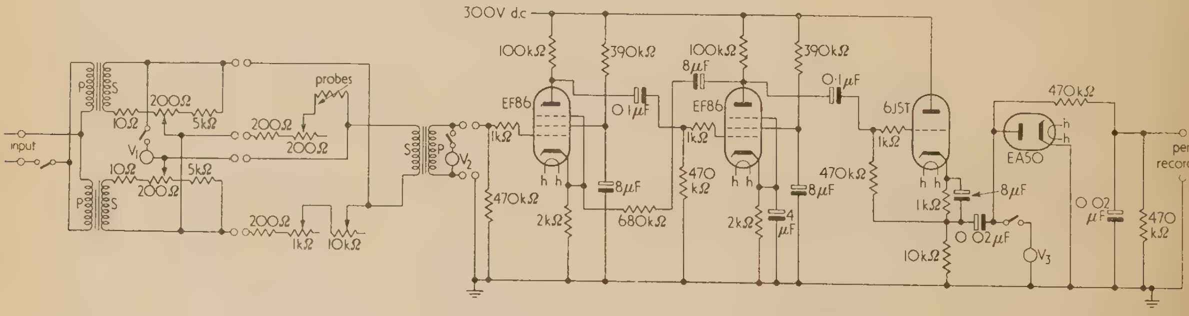

Fig. 2. Circuit diagram of water-wave level detector

The balanced voltage output from each secondary of the step-down transformer is then fed by wander-plugs into a further circuit. In Fig. 2 the top circuit contains the probes n the water, virtually a variable resistance. These probes onsist of two $\frac{1}{8}$ in. diameter brass rods, chromed if desired, pproximately 1 in. apart, fixed to a slider arrangement so hat they can be moved up and down in the water by known mounts. A screw arrangement with say five or ten turns to he inch is found most useful; Fig. 3 showing typical probes.

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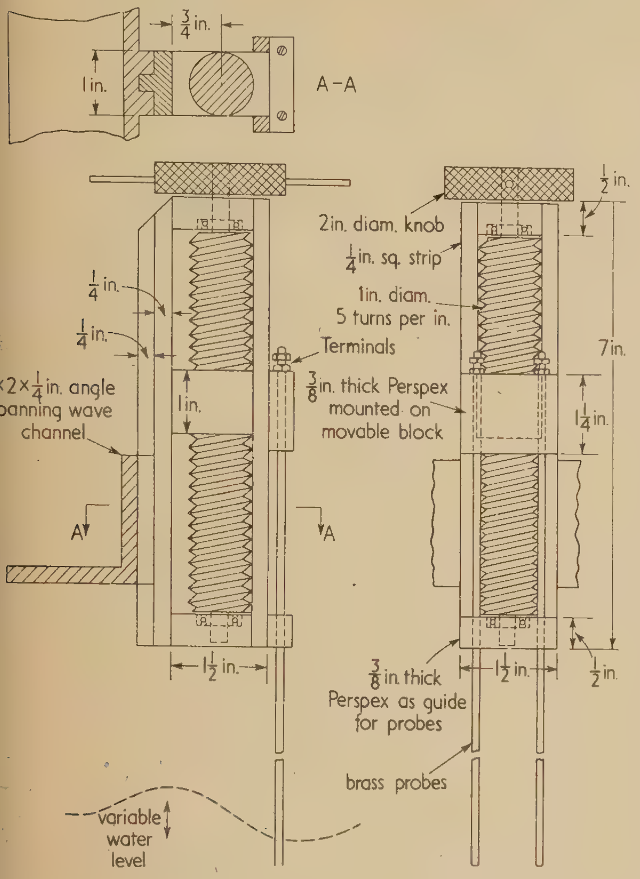


Fig. 3. Diagram of probes and mounting in position

he probes are inserted in the water so that at the trough f a wave approximately one inch of rod is still immersed. t will be seen that as a trough of a wave passes the probes placed in line normal to the wave-front) the resistance is igh, and decreases when the depth of water increases as a esult of the crest of the wave passing the probes. By nserting the probes in still water to a depth greater than the mmersion caused by a wave-crest, the probe resistance can e equated by the potentiometers on the bottom of the etector circuit (Fig. 2) so that the current flowing into the utput transformer is nominally zero. The output transormer, of the same value as the two input transformers, is sed primarily to eliminate any stray d.c. component picked p by the probes in the water and to give some amplification f the output of the detector circuit. The output voltage, aving a value between zero and 0·1 V is now fed to the mplifier and rectifier.

AMPLIFIER AND RECTIFIER

This is a normal two-stage amplifier using low-noise audio-equency pentodes with feed-back from the anode of the econd stage. From the second stage the signal is fed to a athode-follower in order not to load the pen-circuit and thence rectified by a diode with a resistance-capacitance network in parallel instead of in series as is usual. The output of the diode is of the order of 0 to 25 V d.c., enough to give full-scale deflexion of the pen recorder.

CALIBRATION OF PROBES

The probes are immersed in still water to a depth about one inch greater than that of the crest of the wave and the detector circuit balanced to give minimum voltage by valve voltmeter V_2 or V_3. By using the variable resistance in the pen recorder the pens are moved to the extreme edge of the recording paper. The probes are now raised in say 0·1 in. intervals, and the paper run for a short distance at each step until the probes are covered by slightly less water than they would be at the trough of a wave. The paper should now have been traversed. If not, the input of the oscillator can be increased until full use of the paper width is being made. The probes are then so adjusted in depth that the pen recorder is approximately at the centre of its travel, and the waves are started.

ACCURACY OF CALIBRATION

Since the apparatus is initially calibrated by moving the probes or, alternatively, raising or lowering the water level by small amounts, and since this is essentially a "static" calibration, the question arises as to the accuracy of the probes in following a "dynamic" or rapid change in water level.

If, in particular, the values of the resistance-capacitance network at the diode stage of amplification are ill-chosen from a theoretical point of view, the pen recorder will either respond too much or too little: the correct shape of varying water level may be given but the amplitude will either over- or under-shoot the correct value. The calibration is done so relatively slowly that this latter effect can most readily be missed.

To check on this the probes were mounted alongside a pair of ordinary pointer gauges. These latter gauges give the mean value of say twenty waves at a frequency of one per second since it takes this time to set the micrometers, and these waves will differ amongst themselves in amplitude by an amount of the order of 2%, since it is virtually impossible to generate waves which are exactly comparable.

Over many hundreds of readings the standard deviation of the micrometers was 1%, the micrometer nominally reading to 0·001 in. The pen recorder accuracy of reading was 0·05 in. and for the same waves the standard deviation was $1\frac{1}{2}$%.

The author is satisfied that this latter comparison does indicate that the probes are capable of giving the correct "dynamic" water level from a "static" calibration. It should be mentioned that over a period of the order of one hour the resistive properties of the water may change slightly and further calibration is required.

CONCLUSION

The author makes no claims as to the originality of such a piece of equipment, the probe concept being a fairly old one. The numerical values, however, may be of some value to any experimenter thinking of using such a system for wave-recording. The apparatus as in use in the Hydraulic Laboratories at the University of Aberdeen is a relatively inexpensive one (apart from the standard electronic equipment of beat-frequency oscillator, pen recorder and power pack for the amplifier), and works extremely well and consistently.

A two-camera technique for measuring fall velocities

By R. H. Magarvey, M.Sc., Department of Physics, Acadia University, Nova Scotia, Canada

[*Paper first received* 6 *November*, 1956, *and in final form* 31 *July*, 1957]

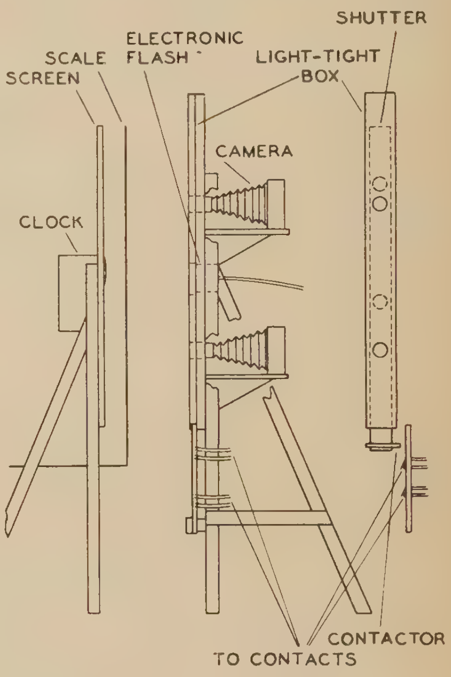
A photographic technique is described that affords data on several phenomena associated with freely falling drops. An essential feature of the technique is a two-camera shutter designed to obtain photographs of the falling drop at two fall distances. Velocities are calculated from a consideration of displacement and time data that appear on the photographs. Information regarding the dynamics of drop deformation is inferred from the geometry of the image pairs and the time interval between photographs. The time interval is dependent on the dimensions and speed of the shutter. The possible error in the calculated velocities of large drops is 2·5%.

Photographic techniques have been used in several studies(1–4) of the physical characteristics of freely falling drops. Much of the apparatus has been designed to measure terminal velocities of drops of various sizes, with little attention being paid to drop deformation processes and the rates at which they proceed. In this paper a simple two-camera technique is described that has been used to obtain data on fall velocities, processes of drop deformation and break-up, and phenomena attending actual drop collisions. The drops are allowed to fall at their terminal velocities in the plane of a centimetre scale and are photographed at two different fall distances. The time interval is read directly from the dial images of a millisecond clock placed in such a position that an image appears on either photograph. For a given geometry of apparatus the time interval is dependent on the shutter speed; the maximum speed is limited by the recycling period of an electronic flash used to illuminate the drop. The maximum time and fall distance between photographs is governed by magnification considerations relative to maintaining the clock in the field of view of either camera.

The technique is particularly useful in obtaining data on the fragmentation of large drops due to free fall break-up by aerodynamic forces. An adjustment of the shutter speed enables the drop to be photographed at identical angles by each camera, thus permitting observations as to the drop geometry and the rate at which it changes.

THE SHUTTER MECHANISM

An independently operated two-camera shutter placed in front of the built-in shutters of the cameras is the working basis of the mechanism. The essential features of the auxiliary shutter are illustrated in the figure. A sliding rectangular plate made from $\frac{1}{8}$ in. opaque Perspex is snugly fitted to the inside of a light-tight box made of the same material. Circular holes in the box walls and plate are spaced in such a manner that light is admitted to the upper and lower cameras in succession as the plate moves downward. A contactor attached to the lower end of the plate triggers an electronic flash when an aperture is formed for either camera by an alinement of holes. The correct alinement sequence results from making the distance between the hole centres in the plate two diameters less than the corresponding distances in the box walls. In the apparatus the holes are cut to accommodate a series VI Kodak lens hood, with a distance between the hole centres of the plate and box eight and ten diameters respectively. Assuming no light is to be admitted to the lower camera before the upper aperture is closed, the minimum distance between the hole centres of the box is four diameters. A minimum distance of two diameters from either end of the plate to the edge of the first hole excludes light from either camera when the plate is not in motion. The accelerating force required to move the plate downward is provided by a coil spring or an elastic band under tension. The shutter speed is varied by adjusting the tension in the spring. The figure shows a manually triggered shutter used to obtain drop photographs with a time interval corresponding to a maximum fall distance of 125 cm at terminal velocity.



Schematic diagram showing essential features of the auxiliary two-camera shutter, and the experimental arrangement for photographing freely falling drops. (Not to scale)

A distance of 50 cm between the cameras affords a magnification of 0·2 with a vertical field of view of 125 cm at an object distance of 80 cm.

OPERATIONAL CONSIDERATIONS

The apparatus was used to obtain photographs of drops up to 10·5 mm equivalent diameter falling at their terminal velocities. The shutter mechanism was placed 80 cm in front of a centimetre scale allowing a depth of field of 10 cm with an $f/16$ diaphragm opening. This depth of field affords sufficient definition to read the clock dial when placed well behind the line of fall. The two $2\frac{1}{4} \times 3\frac{1}{4}$ in. cameras fitted th Kodak $f/4{\cdot}5$, 101 mm Ektar lenses were placed in sition as indicated in the figure.

In actual operation the individual camera shutters are osed until the auxiliary shutter is cocked by moving it into upper position. The aperture of either camera is adjusted $f/16$ and the shutter held open with a time bulb and instan- neous cable release. The auxiliary shutter is triggered anually, allowing the two cameras to take photographs in ccession as the contactor triggers the light. When the plate s moved to its lower position, the camera shutters are ipped with release cables, the hinged switch panel is swung ide and the plate moved into its upper position as before. ne falling drops are illuminated by a type 1532 Strobolume ght triggered by the contactor on the moving plate. The μs duration of this high intensity light is sufficient to stop e motion of the falling drops.

To minimize reflexion difficulties the dial of the clock is aced behind a curved glass window made of a 15 cm watch ass. The screen is covered with a waterproof transparent astic sheet with a water-tight seal around the window. The ock used with this arrangement was a type M.S.T. (by andard Electric Time Co.) operated from a 110 V a.c. line nd a 12 V d.c. supply for the clutch control.

LIMITATIONS OF THE TECHNIQUE

As the hand of the clock makes one revolution in 360 ms, e angular displacement of the hand in degrees is a direct ading of the time between photographs in milliseconds. ith proper magnification the position of the indicator can e read directly from the negative to within 1 ms. Possible rors of 2 ms in the time interval and 5 mm in the fall istance between photographs result in a possible error of ·5% in the calculated velocity of a large drop falling at a rminal velocity of 10 m/s and photographed at an interval f 100 ms. The error in the velocities for small, slowly moving drops is kept within these limits by regulating the time interval between flashes of the light. The minimum recycling time of 0·5 s for the electronic flash imposes an upper limit on shutter speed for any given geometry of apparatus. As the drops are photographed at terminal velocities a more practical consideration is a depth of field permitting the line of fall to be nearly 10 cm in front of the screen and clock dial. As magnification is sacrificed for depth of field for a given diaphragm opening, the experimental arrangement described in this paper is an acceptable compromise. Drop processions produced by a sensitive jet-type drop generator(5) have been used most successfully with a manually operated mechanism. The drop profile is more pronounced when a trace of aniline dye is added to the water forming the drops.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. Borden W. Taylor for his help in constructing and testing the shutter mechanism, and the Nova Scotia Research Foundation for making the project possible.

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Laboratory and workshop notes

Simple greaseless valves

By E. RAATS, M.Sc., Ph.D., National Chemical Research Laboratory, Pretoria, and J. HARLEY and V. PRETORIUS, M.Sc., D.Phil., University of Pretoria, S. Africa

[*Note received* 2 *April*, 1957]

In the study of gas-phase reactions, it is often undesirable to use conventional greased stopcocks, as the lubricant tends to absorb or contaminate the gases. Greaseless valves are commercially available but are frequently beyond the means of a small laboratory.

Simple and efficient valves may be easily constructed from glass tubing, steel or brass rod, and polyethylene or polyvinylchloride tubing. The polyethylene and polyvinylchloride are chemically inert and the former is conveniently worked on a lathe. The constructional details are shown in the figures. Very few of the dimensions are critical—satisfactory valves have been made from glass tubing varying from 8–30 mm in diameter.

Under pressure, the polyethylene "wets" the glass. Accordingly, the polyethylene plugs should fit very tightly into the glass tubing to ensure a gas-tight seal.

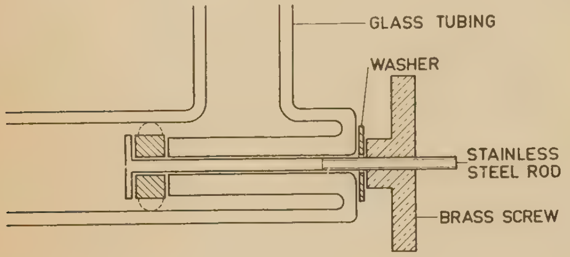

Fig. 1

In the valve shown in Fig. 1, a short length of elastic, heavy-walled tubing (e.g. rubber or polyvinylchloride), is compressed until it seals against the glass walls. The annular space between the tubing, in the normal position, and the glass walls should not exceed a millimetre, otherwise the movement of the screw, when closing the valve, is excessive. A lock-nut is used to prevent the valve from being opened too far, as this would open the valve to the atmosphere.

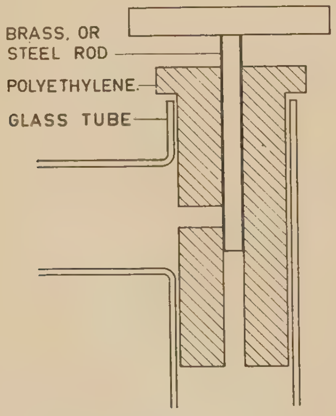

Fig. 2

A gas-tight fit between the threads of the metal rod anc the plug of the valves shown in Figs. 2 and 3 is ensured by drilling and threading the hole in the plug slightly smalle than the rod. The rod is warmed to about 100° C anc carefully worked into the polyethylene threads.

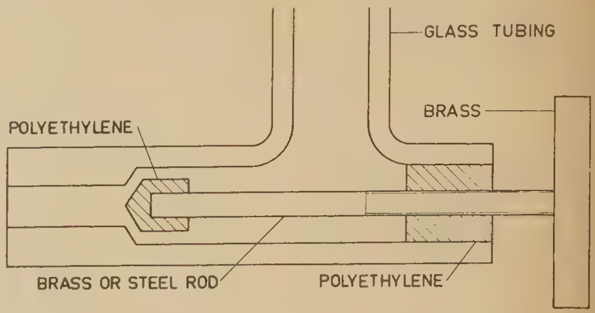

Fig. 3

If the contact of gas with the metal rod in the valve i undesirable, it may be avoided by use of the valve shown i Fig. 4. On turning the valve, the movement should not exce a millimetre, otherwise the polyethylene appears to lose it elasticity.

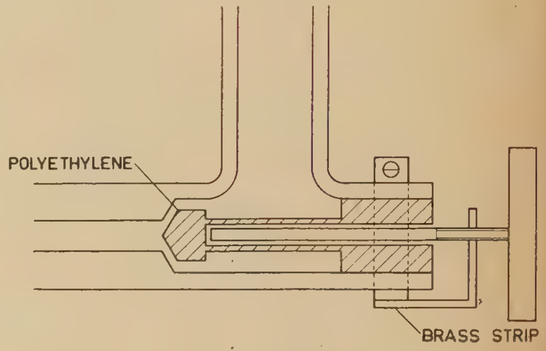

Fig. 4

The valves shown in Figs. 5 and 6 are similar in design t the valve shown in Fig. 2, except that in these valves contac of the gas with metal parts is also avoided. The inner surfac of the plug of the valve shown in Fig. 5 should be carefull

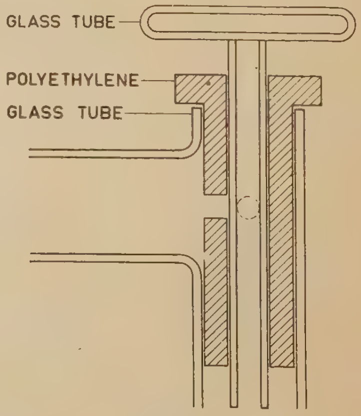

Fig. 5

oothed after being turned on the lathe. This may be done slightly warming the glass before inserting into the plug. ne outer surface of the plug shown in Fig. 6 should be nilarly treated.

The valves shown in Figs. 7 and 8 work on a slightly different inciple. The valve in Fig. 8 may be used only at relatively w pressures. A thin sheet of polyvinylchloride is pressed ainst the inlet and outlet orifices by means of compressed r. The valve is opened by evacuating the reservoir.

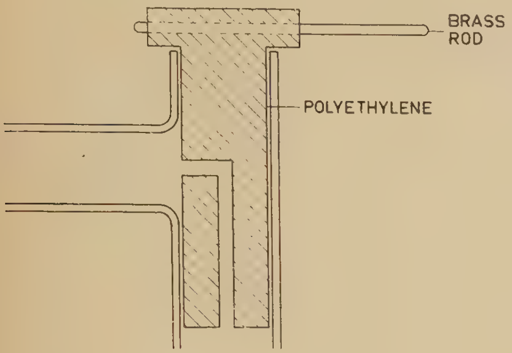

Fig. 6

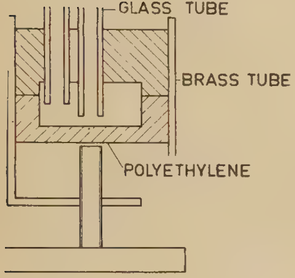

Fig. 7

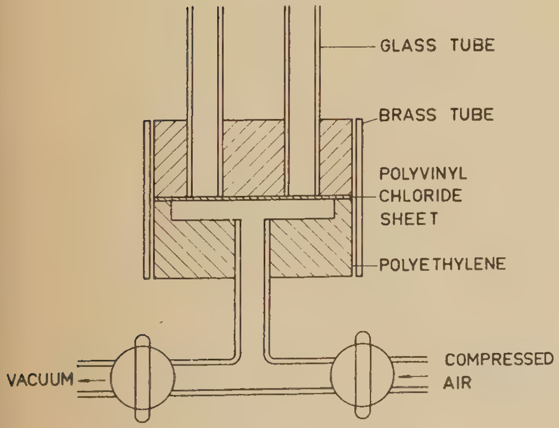

Fig. 8

It should be pointed out that plastic materials contain latile plasticizers and the valves described might be unsuitle in certain applications where a high degree of gas purity required.

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An extension to the range of the McLeod gauge

By J. A. Barnard, Ph.D., A.R.C.S., Department of Chemical Engineering, University College, London, W.C.1

[*Note received* 14 *May*, 1957]

In some work on adsorption it was necessary to measure accurately pressures from 10^{-2} to 300 mm of mercury. The upper part of this range 15–300 mm is readily covered using a wide-bore manometer and a cathetometer, but pressures in the range 10^{-2}–15 mm are difficult to measure accurately with a single instrument, particularly if the use of low vapour pressure low density liquids, e.g. dibutyl phthalate, is not possible. However, such measurements can be made with a McLeod gauge of conventional design if a correction is applied to the readings in the upper part of the range.

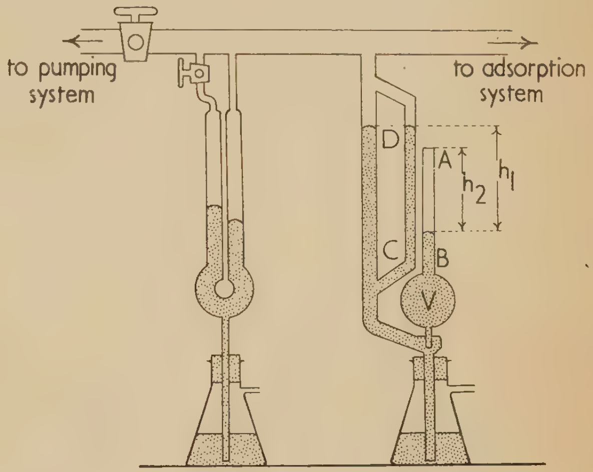

Diagram of apparatus

In normal circumstances the McLeod gauge is simple to operate. A mass of gas is entrapped in the volume V and compressed into the closed tube AB. If we arrest the rise of the mercury at D then the volume of gas in the uniform bore tube AB is $h_2 \times a$ (where a is the cross-sectional area of the capillary), and its pressure is h_1. Then if p is the initial pressure of the system (i.e. the pressure at which the original mass of gas was entrapped in V) by Boyle's Law

$$p = ah_1h_2/V \tag{1}$$

Thus knowing a and V, and by measuring h_1 and h_2, which are generally $\geqslant$ 1 cm, we may calculate p.

This is only true if the pressure in the system when the mercury is raised is negligible in comparison with h_1. If it is not then a correction must be applied.

Suppose the pressure in the system with the mercury in the McLeod gauge lowered is p cm, and the pressure with the mercury raised is p' cm; $p' > p$ since a diminution of volume of the system has occurred. The ratio p'/p will be constant, however, provided that the mercury is always raised to the same height in the open limbs of the gauge and that the volume of the rest of the system remains constant. This ratio k, may be accurately determined by manometer readings at pressures in the cm range, as the ratio will be independent of pressure if the gas obeys Boyle's Law. Now when the pressure in the system is no longer negligible

$$pV = h_2a(h_1 + p')$$

since the pressure exerted on the gas in the capillary is the sum of the pressure due to the head of mercury of height h in the column CD and the pressure of the gas in the system. Thus

$$p = h_1 h_2 a/(V - kh_2 a) \qquad (2)$$

This equation has been tested as follows. The pressure of gas in the system was measured using equation (2). The gas was kept entrapped in the McLeod gauge, but the remainder of the system was evacuated. When the pressure was reduced to below 10^{-2} mm, h_1 and h_2 were remeasured and the initial pressure of gas calculated using equation (1). The results of two typical experiments are shown below.

Results showing pressures obtained in two typical experiments

From equation (1) *mm of mercury*	*From equation* (2) *mm of mercury*
10·06	10·04
11·50	11·46

The equation (2) is thus obeyed within the limits of accuracy of the experimental readings, and when used in the way described the useful range of the McLeod gauge is extended up to pressures of the order of 2 cm of mercury.

A simple specimen holder and apparatus for measurement of conductivity and Hall voltage over a temperature range

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[*Note received* 26 *June*, 1957]

In the expanding field of semi-conductor research there is a growing need for routine measurements of conductivity and Hall coefficient over a wide temperature range. These electrical measurements are usually made on single crystals and provide information on their electronic properties and also serve as a check on the growing conditions and reproducibility of the crystals. Such measurements have been carried out by Putley[1, 3] and others using a method of mounting the specimens in an elaborate holder. This involved a complicated procedure requiring skill and experience. The electrical connexions to the specimen were made by welding or soldering fine wires at the appropriate points on the crystal as described by Mitchell.[2] The holder described here is simple to make and does not require the highly skilled operations of welding or soldering.

It can also be stated here that experiments carried out in this laboratory have shown that, with certain semi-conductors in a highly purified state, the welding of connecting wires has affected the surface properties of the crystal sufficiently to make the measurements incorrect. The present holder employing spring contacts does not damage the surface to any extent and hence the correct characteristics of the crystal are obtained on measurement.

Details of the specimen holder used in the present work are shown in Figs. 1 and 2. A Tufnol platform (Fig. 1) of

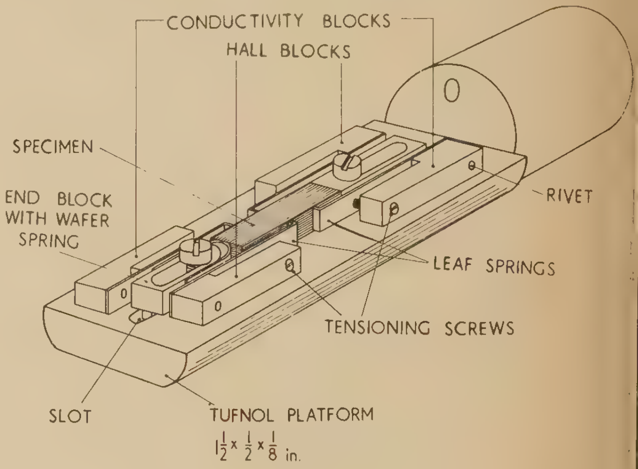

Fig. 1

dimensions $1\frac{1}{2} \times \frac{1}{2} \times \frac{1}{8}$ in. is used to carry the contact block for specimen connexions. The end blocks carrying the direc current are rectangular in section with locating pins whic slide in appropriate slots in the base. The crystal contact t one of these is through a small wafer spring which takes u any expansion differences throughout the temperature rang The conductivity and Hall blocks are also rectangular an contact is made to the specimen *via* leaf springs of 0·008 in beryllium copper riveted to shoulders on these blocks. Th springs can be adjusted by 14 B.A. tensioning screws an must have clearance from the base. The conductivity con nexions are made on opposite sides of the specimen fo

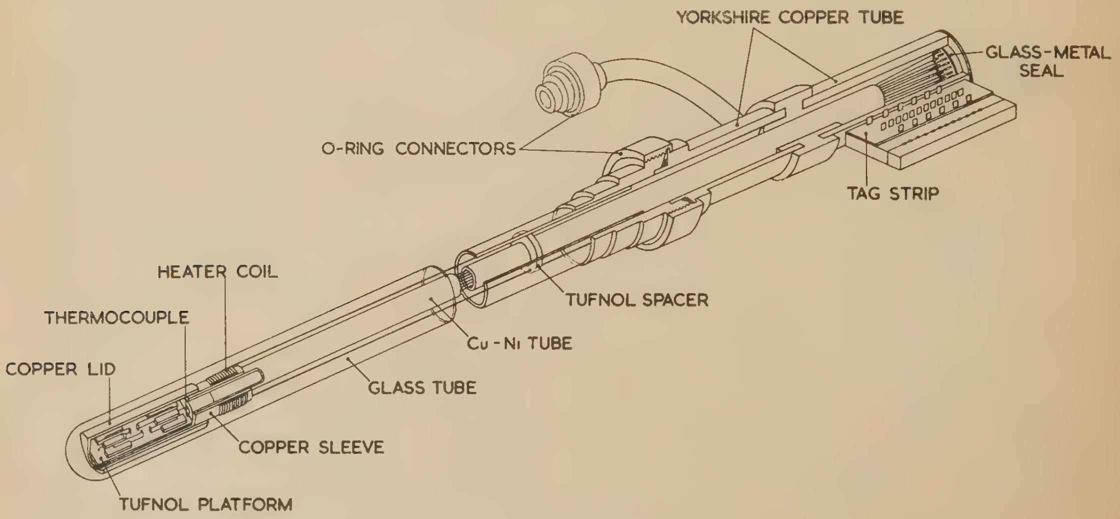

Fig. 2

venience, as shown. All screws and blocks are made of ss and all metal parts are rhodium plated. For high perature work the base can be made of pyrophyllite. . 2 shows the complete construction of the holder. The e is fixed into the end of a cupro-nickel tube about 24 in. g, 0·4 in. in diameter and with a wall thickness of 0·008 in. ached to the end of the tube is a copper sleeve which ries a heater coil and copper lid. The lid is made to round the specimen and keep the enclosed space at as form a temperature as possible. The cupro-nickel tube ixed to a sleeve inside the upper end of the holder which is de from ¾ in. diameter Yorkshire copper tube. The necting leads and thermocouple are passed up inside the ro-nickel tube and with the heater connexions are brought *via* a multi-way glass-to-metal seal. An outer glass tube, in. long, 0·8 in. outer diameter, spaced from the cupro- kel tube is attached to the upper part of the holder by ans of an O-ring connector. The inside of the holder can evacuated through the side arm and can also be filled with suitable gas.

The measuring apparatus used was similar in principle to t reported by Putley.(1) A multi-point print wheel tentiometer recorder was used, the channels being allocated the following sequence: (1) temperature; (2) conductivity h normal current direction; (3) conductivity with reverse rent; (4) Hall voltage with normal current and normal d direction; (5) Hall voltage with normal current and erse field direction. The current and field reversing itches were coil-operated mercury contactors. The eration of the various switches and contactors was carried t using a multi-bank uniselector impulsed from a micro- itch attached to the print wheel mechanism of the recorder. is arrangement ensured that the operations were always in p with the recorder. In both Hall and conductivity circuits injected voltage was used to make the recorder effectively entre zero instrument. It is very unlikely that in an actual asurement both the Hall voltage and conductivity voltage ll be the same order of magnitude, with the same specimen rrent. It is therefore necessary to arrange a potential ider in one circuit, Hall or conductivity, whichever gives greater voltage, to ensure that both voltages are accom- dated conveniently on the recorder. A copper-constantan rmocouple was used to give the temperature record. the output from the thermocouple at low and high nperature was greater than the full-scale deflexion of the order, a voltage was injected in the thermocouple circuit give a suppressed zero effect on the recorder. This injected ltage was measured on a potentiometer and added to the order defection. The sensitivity of the recorder used was 5 mV full scale. With this arrangement a clear record of changes of Hall and conductivity voltage with temperature btained.

This holder has been used repeatedly from 20 up to 500° K. e rate of warming up from low temperature can be ulated by the small heater coil (24 V, up to 100 mA) on copper sleeve. It is convenient when making a tempera- e run from 20° K to fill the space inside the outer glass e with hydrogen gas, as its high thermal conductivity bles the specimen to attain a uniform low temperature y rapidly. To reduce the initial rate of warming up from K it is possible to remove this hydrogen gas and evacuate holder. The average time for a run from 20° K to room perature is about 1½ hours, but this can be regulated to t the particular specimen being measured.

The holder and apparatus described has been used for king routine measurements on many semi-conducting crystals of varying characteristics and has proved very reliable and satisfactory. The ease of insertion and replacement of specimens with the use of spring contacts has resulted in a considerable saving of time.

Acknowledgement is made to the Controller of H.M. Stationery Office for permission to publish this note.

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The cleaving of mica in water

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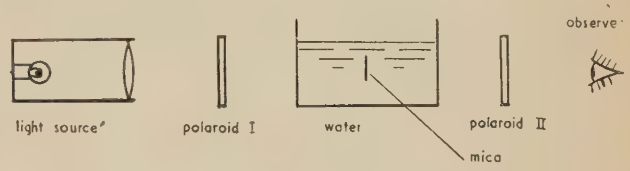
[*Note received* 28 *June*, 1957]

It is well known that mica can easily be cleaved in water to yield very thin and homogeneous layers. However, the thinner the layers, the more difficult it is to handle them, mainly because they are poorly visible in the water. It is hardly possible then to keep a homogeneous thickness or to tell *where* only a part of the layer has been cleaved. To facilitate the process the following method was used (see figure).



Set-up to observe thickness of mica

A beaker containing water is illuminated by a polarized light obtained by inserting a polaroid filter between the light source and the water. When this is viewed through another polaroid filter, at right angles to the first one, the glass and water appear dark. On this background the mica, which rotates the plane of polarization, is much brighter and can easily be seen. This facilitates the handling.

Since the rotation of the plane of polarization depends on the thickness of the mica, very small differences in thickness are distinguishable to the eye by means of their relative brightness. It is possible then to obtain homogeneous layers such that it is possible by weighing them to get a good estimate of their thickness. Using this method, good layers of 0·8 mg/cm^2 were easily cleaved.

A simple and inexpensive emission regulator for ionization gauges

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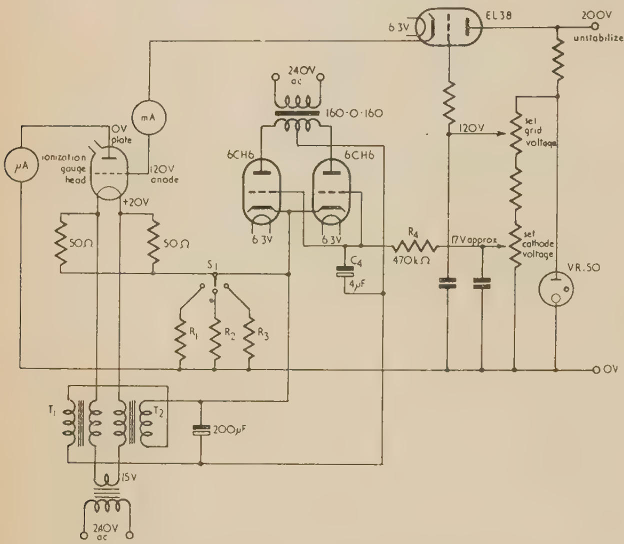
[*Note received* 4 *June*, 1957]

The ratio of positive ion current to electron current in an ionization gauge is proportional to the pressure, so that, by keeping the electron current constant, the pressure may be determined directly from the positive ion current. It is, therefore, desirable to control the filament current of an ionization gauge to give a constant electron emission. Since changes in pressure often affect the emission of the filament, an automatic regulator is by far the most convenient way of keeping the electron current constant, and makes the gauge particularly useful for continuously monitoring pressure in a vacuum system. There are available a number of commercial regulator units, but these are usually rather expensive. A large number of regulators have been described in the literature,(1–5) but that described here(6) is exceedingly simple and made from readily obtainable components.

The complete ion gauge control unit contains an electrometer circuit for measuring the ion current and provision for reactivating the gauge head. The regulator circuit is of most interest, however, and therefore is the only part of the unit described in detail. The regulator is a conventional servo system and is shown in the figure. The output is the voltage developed by the electron current in the gauge head across one of the resistors R_1, R_2 or R_3, which can be switched by S_1 to give electron currents of 1, 5 or 20 mA. This voltage is applied to the cathodes of two 6CH6 valves, which serve as a grid controlled biphase rectifier. The reference voltage is derived from a VR 150 stabilizer, and is fed to the grids of the 6CH6 valves *via* R_4. The output current from the grid control rectifier is passed through the high impedance windings of two cheap 7 W loudspeaker transformers, T_1 and T_2, which serve as transductors to control the current in the gauge filament. The transductors are connected in the usual manner, i.e. so that only harmonic voltages appear across the two controlled windings, and these voltages are short circuited in the usual manner by a 200 μF electrolytic capacitor. The cores of the transformers should be stripped and fully interleaved to facilitate saturation (cores of output transformers are seldom fully interleaved when received).



Basic circuit of emission regulator

The regulator will tend to oscillate, because of the long thermal time constant of the gauge filament and the time constant of the transductor circuit. To make the circuit stable, a capacitor C_4 is connected between the output and input of the grid controlled rectifier circuit. This, in conjunction with R_4, introduces an integral term in the transfer impedance and reduces the loop gain at frequencies where there is a large phase shift. To obtain the required value for C_4 the capacitance was increased until the circuit was quite stable, then doubled, to give adequate stability. The response of the regulator to a step input is a damped oscillation of about 0·5 c/s. The positive voltage to the anode helix o the gauge head is stabilized by a simple cathode followe and the positive ion current to the earth plate can be measure either by a micro-ammeter or an electrometer circuit.

In the complete instrument, switching is provided to connect the anode and plate of the gauge head together and dra large currents for reactivation and degassing, but thes details are not shown in the circuit. The only precaution t be observed in this connexion is that the switch wafer connected to the plate should be the ceramic type, to minimiz leakage.

The regulator was designed to stabilize the electron curren to about ±5%. It has, however, kept the emission of th gauge head used with it constant to better than ±2½% f a period of about two years, without any attention whatsoever. At the end of this period the emission of the gaug filament fell considerably, taking it beyond the control rang of the regulator. It was found that, by changing the tapping on the a.c. sides of the transductors so that they presented lower inductance, the 20 mA emission was regained. However, the gauge head was in any case nearing the end of i useful life, and shortly afterwards had to be replaced becau of lack of emission.

The circuit described, whilst very simple and inexpensiv will effectively regulate the emission of an ionization gaug filament to a degree satisfactory for most high vacuu laboratory work.

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A re-entrant cavity for magnetic measurements

By E. A. FAULKNER, Research Laboratories, General Electric Co. Ltd., Wembley, Middlesex.

[*Note first received* 13 *June, and in final form* 24 *July*, 1957]

This type of open-ended resonant cavity was designed f the measurement of the magnetic permeability of sma toroidal specimens in the range 250–3300 Mc/s. Althoug its construction is simple, it gives more accurate results th the usual standing-wave method and, furthermore, it is ve much easier to use.

The tuning rod is lubricated with graphite grease and do not rely on metallic contact; its action is very smooth. T clamping bush and nut, which enable the position of t central conductor to be adjusted, are of the kind used f locking pre-set controls and are easily available.

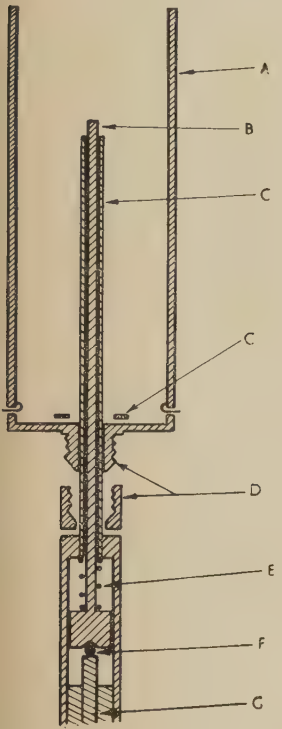
The apparatus is used in the following way. The specim is inserted to rest on the end wall of the cavity in a positi which, judged by eye, is coaxial with the central conduct This adjustment is not critical. A stable signal generat and a crystal detector are connected to the input and outp coupling loops respectively, and the position of the centr conductor is set to obtain a response from the detector. Th constitutes a first rough tuning of the resonator, after whi the central conductor is clamped in position. The micromet adjusted until resonance occurs, and the micrometer adings x_1 and x_2 are recorded corresponding to the half- wer points. The specimen is then removed and the same ocess is repeated, giving readings y_1 and y_2. The com- nents of the complex permeability of the specimen are ven by

$$\mu' = 1 + \frac{(x_1 + x_2 - y_1 - y_2) \cdot \log^2 B/A}{2t \cdot \log B/C \cdot \log b/a}$$

$$\mu'' = \frac{(x_1 - x_2 - y_1 + y_2) \cdot \log^2 B/A}{2t\,.\,\log B/C\,.\,\log b/a}$$

iere A = radius of central conductor
B = radius of outer conductor
C = radius of tuning rod
b, a = radii of specimen
t = axial thickness of specimen.

The cavity used in the range 250–1000 Mc/s has an outer nductor 32 cm long and 4·8 cm in radius. For the higher



A re-entrant cavity for magnetic measurements

A, brass tube; *B*, $\frac{3}{16}$ in. brass rod (tuning rod); *C*, $\frac{1}{4}$ in. brass tube; *C*, thin toroidal specimen; *D*, split bush and locking nut; *E*, spring; *F*, steel ball; *G*, micrometer head.

quencies (1000–3300 Mc/s) a smaller radius is necessary if coaxial mode is to be maintained, and the outer conductor the cavity used in this range is 11 cm long and 2·3 cm in dius. Apart from the outer conductor and the length of inner conductor, the two cavities are identical.

These cavities can also be used for dielectric measurements, d as wavemeters for the absolute measurement of small anges of frequency.

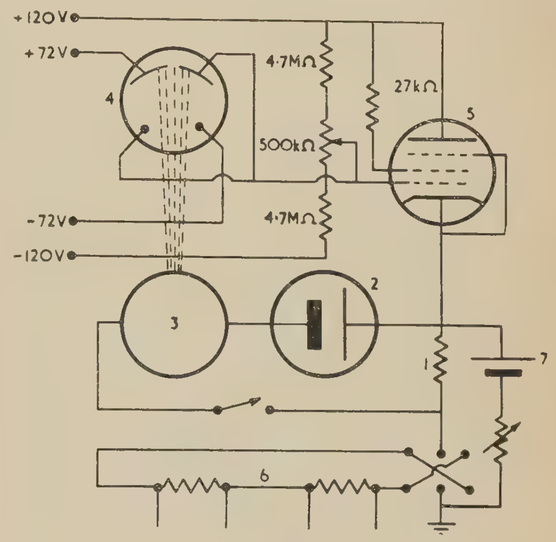
current regulator to facilitate resistance measurements at low temperature

3y M. W. Thompson, B.Sc., Metallurgy Division, Atomic Energy Research Establishment, Harwell, Berks.

[*Note first received* 2 *July, and in final form* 2 *September*, 1957]

making accurate measurements of small resistances of the ler $10^{-2}\,\Omega$ at low temperature, the chief source of error has been found to be variations in the temperature of the leads. Since these leads have to pass from within a cryostat to the measuring apparatus at room temperature they are of comparatively high resistance in order to reduce thermal leakage. Bridge circuits are frequently unsuitable under these conditions and a potentiometer is often used to compare the potential drop across a specimen with that across a standard resistance carrying the same current. However, if an accuracy of better than 1 in 10^3 is attempted, the variation in the resistance of current carrying leads may be sufficient to cause considerable changes in potential during the time required to take a reading. It was therefore decided to construct a current regulator which would maintain a constant current regardless of lead resistance.

The regulator shown in the diagram depended on the comparison of the potential drop across a fixed resistance (1) with that of a Weston standard cell (2). Any difference in potential caused a deflection of the galvanometer (3) whose spot moved over the two halves of a GS149 gas-filled double photocell (4).



Current regulator circuit

In order to obtain maximum sensitivity the "spot" of the galvanometer was made of such a size and shape as to separately cover either cathode of the photocell. The photocell was connected in the grid circuit of an EF37A pentode valve (5) whose cathode current formed a part of the current to be regulated. By arranging the galvanometer polarity in such a way as to obtain negative feedback it was possible to achieve an accurately regulated current.

As the cathode current of the valve was only 3 mA the major part of the current in the resistance circuit (6) was supplied by a lead-acid accumulator (7). With a fixed resistance (1) of 20 Ω a total regulated current of 50·9 mA was obtained. Using a 4·4 Ω galvanometer having a sensitivity of 33 mm/μA the regulated current was constant to 1 part in 10^5 for periods of 10 minutes or more.

In a galvanometer-photocell circuit with heavy feedback the galvanometer period is greatly reduced, often resulting in the galvanometer becoming sensitive to vibrations normally found in a building. It was therefore necessary to mount the galvanometer on a rigid platform. For the same reason it was considered advisable to use dry batteries rather than to risk oscillations being set up by the mains frequency ripple of a rectified h.t. supply.

NOTES AND NEWS

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improvec products. The Institute of Physics assumes no responsibility for the statements given below: information for these has beer taken from literature supplied.

Electron microscope. North American Philips Co., Inc., 750 Fulton Avenue, Mount Vernon, New York, U.S.A.

The type EM-100B electron microscope, illustrated in the figure, is stated to have a guaranteed resolving power better than 20Å. The objective lens is hinged so as to enable the pole inserts to be easily removed for changing or cleaning. When the objective is fitted with pole inserts for high resolution, the magnification can be continuously adjusted from the control panel through the range ×5000 to ×100 000. The corresponding range when diffraction pole inserts are used is ×1750 to ×35 000. The magnification can be doubled by the camera equipment. The actual magnification is indicated directly on a panel meter, and a micron marker makes a corresponding reference scale on the film or plate negatives. The objective is fitted with an astigmatic compensator of the magnetic built-in type, which is externally adjustable during operation. The objective diaphragm, with multiple apertures in the front focal plane, is adjustable from outside and can be removed for cleaning without dismantling the lens system.

Electron microscope

For visual work, the 8 in. viewing screen shown in the figure serves for all magnifications. By means of a binocular attachment, the image can be enlarged ten-fold. An alternative special insert screen with binoculars enables the image to be viewed at lower beam intensities, a valuable feature when working with thin biological specimens. The recording facilities include a 35 mm camera, giving thirty-six exposures on a standard film, and a cassette holding five plates of size 4 × 3$\frac{1}{4}$ in. Stereoscopic micrographs are made by manipulation of the specimen holder.

Electron diffraction patterns can be made by the selected area technique from areas measuring from 1 to 30 μ Externally controlled diffraction apertures are used to selec the area of the specimen for examination. An accessory i also available for reflexion diffraction work.

The accelerating voltage can be set during operation a 40, 60, 80 or 100 kV. The lens currents are automatically adjusted to correspond with the accelerating voltage. In addition to the normal focusing device, there is a through focus control to provide a reproducible amount of deviatio in either direction from exact focus. The electron beam i alined by two transverse magnetic fields.

As can be seen from the figure, the microscope column i mounted in a nearly horizontal position for normal use A built-in cranking mechanism erects it into a vertica position for servicing. The pumping system is arranged s that the mechanical pump is not in operation when th instrument is used, thus eliminating vibration. An air-loc in the specimen chamber enables the specimen to be change with vacuum recovery in 20 s. The evacuation time afte changing filament or camera, or when starting from co is 15 min.

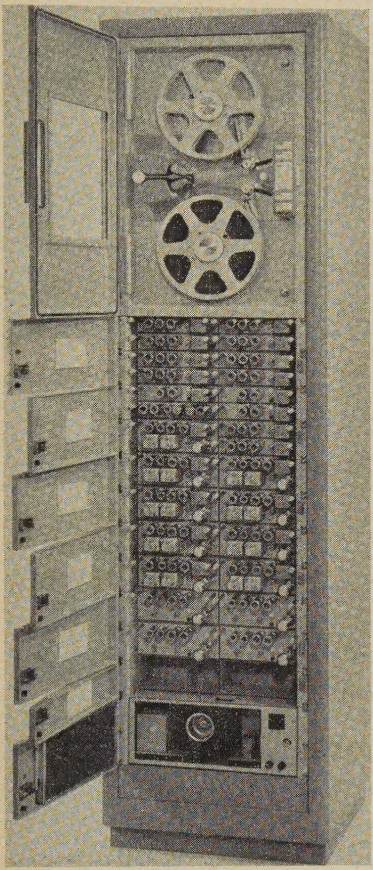
Sub-miniature electrolytic capacitors. The Plessey Co. Ltd Ilford, Essex.

A new range of aluminium sub-miniature electrolyti capacitors is intended for use in circuits using transistors such as hearing aids, where small size is essential. Th smallest capacitor is only 0·1 in. diameter and 0·45 in. lon including spigots. It is stated that a new method of securin the wire terminations to the anode riser prevents the poss bility of dissimilar metals making contact inside the case, thu eliminating corrosion in the presence of the electrolyte. Th capacitors are available in capacities from 1 to 50 μF an for operation at peak voltages from 1·5 to 70 V. They ca be supplied in four case sizes and are suitable for use in th temperature range −15 to +60° C at working voltages u to 40 V d.c. and from −30 to +60° C at higher workin voltages.

Magnetic tape recorders. Ampex Corporation, Instrumentation Division, 934 Charter Street, Redwood City California, U.S.A.

An extensive range of specialized tape recording equipment now available for rack mounting. A unit type of constructio enables the equipment to be adapted to individual requirements. The machine takes standard $\frac{1}{4}$, $\frac{1}{2}$ or 1 in. tape, an is driven by an a.c. synchronous motor which derives power from a l.f. oscillator using a Wien bridge or crystal t control the frequency. It is possible to record as many a fourteen tracks on the tape; this feature is particular valuable for the storage of data. The circuits can be arrange for amplitude, frequency or pulse-width modulation. Typica figures for amplitude modulation are a pass band unifor

3 dB from 50 c/s to 60 kc/s for a tape speed of 30 in./s. sing frequency modulation, with a tape speed of 60 in./s, e response is uniform to 1 dB over the range 0–10 kc/s and ere is a 50 dB signal-to-noise ratio. Pulse-width modulation used to record a large number of low frequency data on a ngle tape track as a sequence of pulse durations. A rotating ommutator continuously scans any desired number of trans- ıcers up to ninety. Their momentary voltages determine ılse durations between 90 μs for minimum voltage to 50 μs for maximum voltage. The frequency response of ıch a system is determined by the sampling rate, and is c/s for thirty data channels and a sampling rate of 900/s. or the storage of data for electronic computing machines, a pecial tape driving unit is made. This is designed so that ıe tape can be started or stopped in 5 ms, the operating peed being either 15 or 30 in./s. Up to seven tracks can be ccommodated on a ½ in. tape and the maximum time-isplacement error between the two outer tracks is stated to e 30 μs at a tape speed of 30 in./s. For some purposes, it necessary that there be accurate speed synchronism between ıe recorded and reproduced data, so that correction must e made for stretching or slipping of the tape. To achieve ıis, a standard 50 c/s signal is recorded on one of the tape acks by modulation of an 18·4 kc/s carrier. When repro- ucing, the apparatus makes a phase comparison between the produced signal and the standard 50 c/s frequency, and regulates the play-back speed to keep the two in synchronism. A highly specialized machine intended for the recording of television programmes is capable of storing a 65 min programme on a single reel of tape 2 in. wide, using a tape speed of 15 in./s. A pass band of 4 Mc/s is required for this purpose and is achieved by using a special magnetic head assembly which rotates at high speed across the tape, thus giving an effective tape speed of the order of 2000 in./s. The sound that accompanies the vision signal is recorded in the ordinary manner along the edge of the tape, so that sound and vision are always in exact synchronism.



Ampex FR–114 magnetic tape recorder and reproducer. Up to 14 data tracks can be recorded simultaneously on the same tape. Direct, frequency modulation or pulse-width modulation can be used

Microwave dielectric test set. Microcell Ltd., 56 Kingsway, London, W.C.2.

The test set illustrated in Fig. 1 is intended for direct readings of permittivity and loss angle using small samples at fixed microwave frequencies. Three different models are available covering the frequency range 6000 to 17 000 Mc/s. Provision is made for dielectric measurements to be undertaken at temperatures up to 450° C. Fig. 2 shows a schematic diagram of the instrument. Energy enters the 3 dB coupler from the

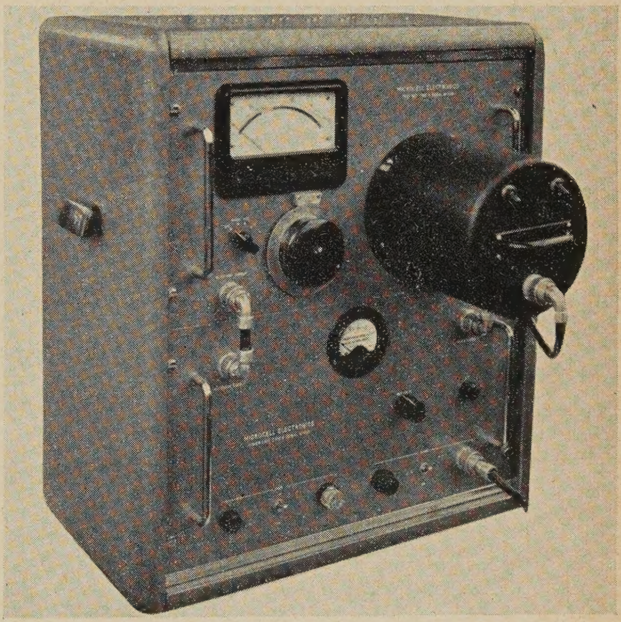


Fig. 1. Microwave dielectric test set

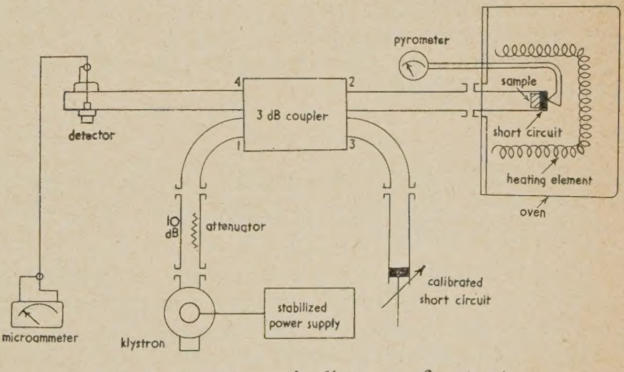


Fig. 2. Schematic diagram of test set

klystron on arm (1). The properties of this coupler are such that the energy divides equally between arms (2) and (3), none emerging from arm (4). Arms (2) and (3) are terminated respectively in a shorting plate and adjustable short circuiting plunger. The plunger is adjusted to give a path difference of 180° between arms (2) and (3). The reflected energy re-enters arms (2) and (3) and is absorbed by the attenuator in arm (1). Insertion of a dielectric sample in arm (2) causes a change in electrical lengths and some of this reflected energy passes to arm (4) which is terminated in a detector unit where output current is indicated on the panel meter. By noting the shift of the plunger necessary to restore the meter reading to a minimum the electrical length of the sample is obtained. This enables the permittivity to be calculated. A measure of the loss angle for the sample is obtained from the difference in amplitude of the reflected waves due to the loss in the sample.

Standard frequency equipment. Airmec Ltd., High Wycombe, Bucks.

The basis of the equipment is a bridge-stabilized crystal oscillator operating at a frequency of 100 kc/s. The crystal is mounted in an oven, the temperature of which is controlled to reduce ambient changes by a factor of 1000. When maximum stability and optimum aging characteristics are required an Essen ring-type crystal is used; if operating conditions are more arduous and stability requirements are slightly less stringent, a GT cut crystal is employed. Two thyratrons are employed in the oven control circuit and either may be removed for replacement without affecting the temperature control. Alarm lamps in each thyratron circuit give continuous indication of the correct operation of the control system. The oscillator, in common with the rest of the equipment, is mounted on a standard Post Office rack. The makers claim a minute-to-minute frequency stability of better than 1 part in 10^{10}, a daily stability better than 5 parts in 10^{10}, a monthly stability better than 1 part in 10^8 and a yearly stability better than 1 part in 10^7. The above figures are for an Essen ring crystal; the figures for a GT cut crystal are not worse by as much as a factor of ten.

The power supply unit for the system incorporates a bank of sixteen individually fused condensers connected in parallel. These maintain the h.t. voltage for a period of several seconds in the event of a mains failure and thus allow time for the stand-by power supply to operate. The latter consists of a 24 V accumulator with trickle charger and rotary converter. This emergency supply is automatically switched on in the event of mains failure.

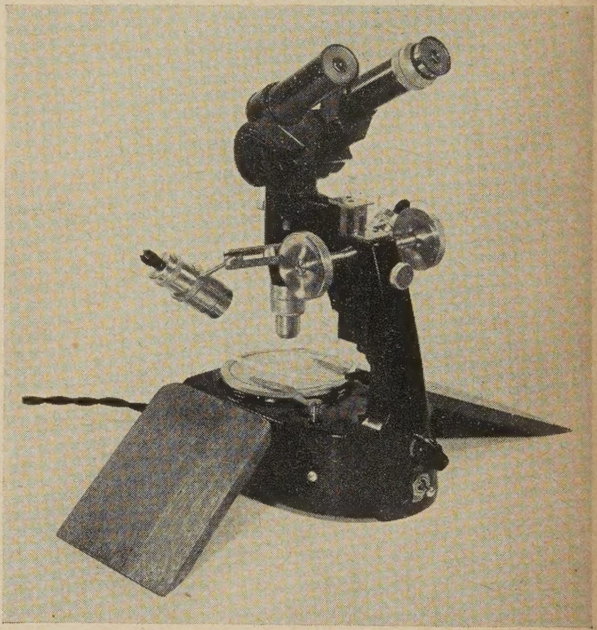
The output of the oscillator is fed through divider units which provide sinusoidal outputs at 10 and 1 kc/s as well as pulses and square waves at 50 c/s. The 50 c/s square wave can be fed into other units to provide 1 c/s pulses and to operate an electric clock.

Crystal oscillator and frequency divider. Ericsson Telephones Ltd., Instrument Division, High Church Street, New Basford, Nottingham.

The type 124 oscillator is a general purpose instrument for laboratory and workshop use. It provides four sub-standard crystal-controlled frequencies, the basic frequency of the 100 kc/s crystal oscillator having an accuracy of 5 parts in 10^5. Four output frequencies are available at front-mounted Belling-Lee terminals. The outputs consist of a 100 kc/s sine wave, derived from the crystal, and semi-square waves of frequencies 10 kc/s, 1 kc/s and 100 c/s derived from multivibrators consisting of one double triode per stage. Three pre-set potentiometers are provided to adjust the division ratio of the multivibrator circuits. These are accurately set before the instrument leaves the works and normally require no further attention. The instrument has its own built-in power supply employing standard full-wave rectification, and it is stated that it retains its stability over a mains voltage fluctuation of ±10%.

Low power stereoscopic microscope. W. Ottway and Co. Ltd., Orion Works, Northfield Avenue, Ealing, London, W.13.

The Orion series of microscopes have been designed on a unit basis so that their range of use can be increased by the addition of units at any time. All models use objectives with the standard R.M.S. thread and also R.M.S. eyepieces, but special objectives have been developed which may be used singly in place of the more conventional double objective system. It is claimed that these objectives give great depth of stereoscopic effect in direct ratio to their focal length.



Low power stereoscopic microscope

Two types of binocular head can be supplied. The simplest form consists of a beam splitting prism and inclined reflector with rack and pinion operation of the inter pupil distance between the eyepieces. Special wide field eyepieces are available for use with this unit and also adapter cells when the use of standard eyepieces is desired. The rhomboid type binocular head is fitted with rhomboid prisms to give an interpupillary adjustment without any alteration of tube length or focus.

The stage of the microscope is a glass disk backed by a Perspex diffuser. A transformer is built into the base for sub-stage lighting and a separate small lamp is available for top light illumination. This lamp can be plugged into a socket on the column of the microscope.

New books

nsductors and magnetic amplifiers. By Dr. A. G. Milnes. (London: Macmillan and Co. Ltd., 1957.) Pp. xiv + 286. Price 63*s*.

is treatment of transductors and magnetic amplifiers is a lcome one written, as it is, by one who has been concerned h their development over the last decade. The approach de is an analytical one, taking the simplest possible alization of the flux relationships in the core material. is method makes it possible to carry out design work ich at least enables one to get near to the desired character- cs. Examples are given of the correlation between cal- ated and experimental values, but the author stresses oughout the book the necessity of carrying out experi- ntal checks to build up design data around particular core nfigurations. The practical aspect has not been overlooked d numerous examples, both general and special, are luded. The final chapter discusses the use of transistors as tifiers for use in auto-self-excitation circuits.

General presentation and style are good and the book ould appeal to all designers and users of these devices.

A. J. Maddock

ltichannel pulse height analysers. By H. W. Koch and R. W. Johnston. Nuclear Science Series. Report No. 20. (Washington: National Academy of Sciences, National Research Council, 1957.) Pp. xi + 205. Price $2.00.

is is an excellent record of an informal conference, held in ptember of last year, on the techniques of pulse height alysis, at which both Europe and North America were presented. Contributions have been arranged in four main oups, the first giving a general review of the subject, basic eas on detectors and problems of pulse shaping. The cond group provides nineteen reports on kick-sorting velopments at the main research centres of the countries presented, including grey wedge, Wilkinson, Hutchinson d Scarrott and added step systems, and discussions of their erits according to the differing requirements of best per- rmance for a given application, reliability and low cost. lse accelerators, for instance, require temporary analogue orage of pulses, with subsequent digital conversion and rmanent storage. Groups III and IV deal with the appli- tion of computer techniques to analysers, calibration and ture trends.

R. A. Pope
W. W. Evans

port of the meeting on semi-conductors, held by the Physical Society in collaboration with British Thomson-Houston Ltd. (London: The Physical Society, 1957.) Pp. 153. Price 12*s*. 6*d*. to members, 20*s*. to non-members.

e report consists of twenty-three papers on a variety of ni-conductor topics. An introductory chapter by Prof. F. Mott deals with crystal models in which the lattice cing can be continuously varied, and predicts a sudden nsition from insulating behaviour to metallic conduction a definite spacing. In other papers, accounts are given of conduction properties, photo-effects, recombination phenomena and nuclear magnetic resonance of indium antimonide, and briefer discussions of gallium arsenide, indium arsenide and bismuth telluride. Surface phenomena on transistor materials are described with special reference to the Ettingshausen Effect and the modulation of surface conductance by external fields. There are further contributions on the technology of silicon, *p–n* junctions, noise generation, high field effects, lifetime-temperature studies and diffusion in lead sulphide. Accurate measurements of thermal conductivity are also described. This is a useful collection of original material which specialists will wish to have readily at hand. Your reviewer doubts whether papers issued in this form will prove as readily accessible in libraries and as readily "quotable" as they would have been if published (say) as a special number of a regular journal.

H. K. Henisch

Instrument technology. Vol. 3. Telemetering and control. By E. B. Jones. (London: Butterworth's Scientific Publications, 1957.) Pp. x + 198. Price 40*s*.

This is the final volume of this work and maintains well the standard set by the previous two volumes. The author continues to give clear explanations of the principles of a type of instrument followed by a detailed description of a few individual examples.

Approximately one-fifth of the book is devoted to telemetering, both pneumatic and electrical, another fifth to the theory of automatic control and the remainder to a very practical description of the method and instruments used. For students he adds some very searching examination questions, but this book has a much wider appeal and can be commended to all who wish to learn about telemetering and automatic control from the user's aspect.

M. C. Marsh

World directory of crystallographers. Compiled by W. Parrish. (New York: Philips Laboratories, 1957.) (Available from: Polycrystal Book Service, 84 Livingstone Street, Brooklyn 1, New York, U.S.A.) Pp. xvi + 79. Price $1.50.

This directory contains short biographical data of 2260 crystallographers from 54 nations. The Directory is arranged in alphabetical order by nations, and individuals within the nations. It gives (i) the full name and title of the crystallographer; (ii) information on the field of study, the university and year of the highest degree; (iii) present position, name of institution and address; (iv) in some cases a permanent or personal address; and (v) major crystallographic interests. Statistical data is also included.

Biographical details for the Directory were obtained by means of a questionnaire sent to persons known to be crystallographers and it includes all details submitted for publication by 20 May, 1957. Additional questionnaires and names received up to 3 June, 1957, are included in a special Late Arrivals section.

R. G. A.

Notes and comments

Publications of the British Standards Institution

The *British Standards Annual Report* has recently been published price 7*s.* 6*d.* Among the achievements it records are sales of more than a million British Standards, and new issues bringing the total number of standards to over 3000. The report contains 270 pages and shows developments over the whole range of industry giving a detailed review of the standards projects completed and in hand for the sixty major industries served. In the comprehensive reports of standards progress in the main industrial divisions of B.S.I. a new system has been introduced into the Report by which readers can see immediately what stage has been reached in the preparation of any particular standard.

Two new British Standards have also recently been published which are: *Memorandum on Therapeutic X-ray equipment* (B.S. 2849: 1957), and *Precise conversion of inch and metric sizes on engineering drawings* (B.S. 2856: 1957). The standards are priced at 4*s.* and 3*s.* 6*d.* respectively. Copies of the publications may be obtained from the British Standards Institution, Sales Branch, 2 Park Street, London, W.1.

Translation of Russian journals

The Pergamon Institute has commenced the translation into English of a number of Russian medical and biological journals. Issues received are as follows: *Journal of Microbiology, Epidemiology and Immunobiology*, Vol. 28, No. 1; *Biophysics*, Vol. 2, No. 1; *Problems of Hematology and Blood Transfusion*, Vol. 2, No. 1; *Problems of Virology*, Vol. 2, No. 1.

The Pergamon Institute, a non-profit-making organization, has recently been formed in New York, and is in the course of formation in London, for the purpose of making available to English-speaking scientists, doctors and engineers from all countries that are members of the United Nations, the results of scientific, technological and medical research and development in the Soviet Union and other countries in the Soviet orbit. Further details may be obtained from the Institute, 4–5 Fitzroy Square, London, W.1.

Semiconductor Electronics

A new periodical has been received which is devoted exclusively to the theory, production, and use of semiconductor material and devices. Entitled *Semiconductor Electronics*, the first issue appeared in January this year. At present, the periodical consists mainly of a monthly survey of the published literature in the field indicated by its title, but its scope will no doubt be enlarged at a later date. Items are classified in such a way as to enable anyone to organize the abstracts into a logical sequence. Further details may be obtained from the publishers, Semiconductor Information Service, Box 407, Cambridge 39, Massachusetts, U.S.A.

The Physics of Fluids

In January 1958, the American Institute of Physics wi publish the first issue of a new journal, entitled *The Physic of Fluids*. The journal will be devoted to original contribu tions to the physics of fluids covering kinetic theory, statistica mechanics, structure and general physics of fluids borderin geophysics, astrophysics, biophysics and other fields of science The scope of these fields of physics includes: magneto-flui dynamics, ionized fluid and plasma physics, shock an detonation wave phenomena, hypersonic physics, rarefie gases and upper atmosphere phenomena, physical aeronom transport phenomena, hydrodynamics, dynamics of com pressible fluids, boundary layer and turbulence phenomen liquid state physics and superfluidity.

The journal will consider appropriate for publicatio original papers containing sufficiently significant results n published in any other recognized publication. It will st as a bi-monthly publication and will be published monthly soon as it appears desirable.

Correspondence on editorial matters should be addresse to: F. N. Frenkiel, Editor, *The Physics of Fluids*, Appl Physics Laboratory, The Johns Hopkins University, Sil Spring, Maryland, U.S.A. Subscription information can obtained from the American Institute of Physics, 335 Ea 45th St., New York 17, New York, U.S.A.

Conference on nuclear fuel cycles

The Institute of Physics has arranged a three-day confere on Nuclear Fuel Cycles to be held at the Institution of C Engineers, London, on 15, 16, 17 January, 1958. Full det may be obtained from The Deputy Secretary, The Instit of Physics, 47 Belgrave Square, London, S.W.1.

British Journal of Applied Physics

Contents of the December issue

CONFERENCE REPORT

Summarized proceedings of the eleventh annual conference of the stress analy Group—Leicester, April, 1957. By A. F. C. Brown.

ORIGINAL CONTRIBUTIONS

The effects of dust and force upon certain very light electrical contacts. By A. Maddock, C. C. Fielding, J. H. Batchelor and A. H. Jiggins.

The breakdown of liquid dielectrics and its dependence on oxidation of t electrodes. By R. Hancox.

Spectral response and linearity of photomultipliers. By H. Edels, and W. Gambling.

Valve instability with cathode standing waves of cylindrical symmetry. W. W. H. Clarke.

Spectral sensitivity of neon discharge tubes. By T. J. Dillon.

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Correspondence

Some carbon replica techniques for the electron microscopy of small specime and fibres. From B. J. Spit; D. E. Bradley.

The application of the centripetal effect in air to the design of a pump. From Popper and M. Reiner.

The flow of gas at very low pressure. From W. Steckelmacher and C. W. Oatl

New books

Notes and comments

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